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Applying Energy Conservation Retrofits to Standard Army Buildings: Project Design and Initial Energy Data

by
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This report describes the initial and continuing efforts in a project demonstrating the energy performance of theoretically-based retrofit packages on as-found, standard-design Army buildings. Four standard building designs are being investigated: a motor vehicle repair shop, the Type 64 (L-shaped) barracks, an enlisted personnel mess hall, and a two-company, rolling-pin-shaped barracks for enlisted personnel. The Army has over 840 of these particular buildings. The objective of the project is to test the energy and cost performance of the retrofit packages, which include such measures as installing wall or ceiling insulation, replacing and/or blocking windows, partitioning areas of differing temperature, modifying air handling equipment, modifying boiler controls, replacing lights, etc. To this end, energy data has been gathered from retrofitted and identical but nonretrofitted buildings for a test/reference comparison.

Preliminary direct energy comparisons show that all packages save a significant amount of energy, but less than anticipated. Some of the discrepancies with original calculations are due to differences between assumed and actual baseline consumption and operating conditions and to changes made to the retrofit packages to accommodate site constraints. Other influences on energy usage in addition to the retrofits include control settings, system efficiencies, maintenance conditions, utilization levels, etc. Further analysis will be needed prior to making final recommendations on the retrofit packages. However, preliminary results suggest that a wide-scale retrofit program using these packages may not be a first priority for energy conservation. Of higher priority may be the improved use and control of existing space conditioning equipment. Results of both direct comparisons and additional statistical approaches will be considered in the future.

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FOREWORD

This work was performed for the U.S. Army Engineering and Housing Support Center (USAEHSC), under Facilities Technology Application Test (FTAT) Project "Energy Conservation Retrofits for Standard Designs." Mr. B. Wasserman, CEHSC-FU, was the Technical Monitor.

This research was performed by the Energy Systems (ES) Division of the U.S. Army Construction Engineering Research Laboratory (USA-CERL). Appreciation is expressed to Mr. Larry M. Windingland, who was the prinicipal investigator during fiscal year (FY) 84 and FY85, and Mr. William R. Taylor, who was the principal investigator during FY86. Ms. Eileen T. Westervelt was the principal investigator during FY87. Appreciation is also expressed to Messrs. Bruce Augustine, Stephen Briggs, John Scanlan, Larry Gibson, and Larry Augustine of USA-CERL for their assistance with instrumentation and data aquisition. The authors also thank the personnel at Fort Carson, CO, in particular COL Henry T. Brown, Director of Engineering and Housing; Mr. Stephen Snyder, Energy Coordinator; Mr. Donald Campbell, Chief of the Heating, Ventilating and Air Conditioning Shop, and Mr. David Brown, field technician.

Dr. Gilbert R. Williamson is Chief of ES. The technical editor was Ms. Jane Andrew, Information Management Office. COL Norman C. Hintz is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.

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1 INTRODUCTION

Background

Each major Army installation needs many buildings of the same functional type, such as barracks buildings, motor repair shops, and mess halls. To minimize design and construction costs, standard construction designs have been developed and used repeatedly for these common buildings, with minor variations in design made to accommodate an installation's mission and location.

Most existing Army buildings, including those of standard design, were built with little emphasis on energy efficiency. These buildings represent possibilities for monetary savings through more efficient space conditioning. The existence of standard construction designs affords opportunity for identifying in a single effort standard energy conservation modifications, or retrofit packages, which may be applicable to numerous Army installations.

To determine the effectiveness of potential standard retrofit packages, computer analyses can be used. Computer procedures can quickly analyze a building layout using representative climatic data. Further, retrofit proposals applied to the buildings can be analyzed for both energy- and cost-saving potentials. Combining computerized procedures with standard designs is effective for analyzing the applicability of standard retrofit packages to buildings in many locations.

The U.S. Army Construction Engineering Research Laboratory (USA-CERL) performed computer-based energy analysis with the Building Loads Analysis and System Thermodynamics Program (BLAST).[1] This analysis developed retrofit packages[2] for increasing the energy efficiency of four categories of standard building designs: a vehicle repair shop, a Type 64 (L-shaped) barracks, an enlisted personnel dining facility, and a "rolling pin" barracks. The Army has over 840 of these particular buildings.

The developed retrofit packages consist of groups of selected energy conservation alternatives, some of which are appropriate only in specified climates. This "standardization"* in retrofit packages has several benefits. Standardization has been shown to

[1] D. C. Hittle, *The Building Loads Analysis and System Thermodynamics (BLAST) Program, Version 2.0, Users Manual, Vol I and II*, Technical Report (TR) E-153/ADA072272 and ADA0722730 (U.S. Army Construction Engineering Research Laboratory [USA-CERL], June 1979); D. Herron, G. Walton, and L. Lawrie, *Building Loads Analysis and System Thermodynamics (BLAST) Program Users Manual — Volume I Supplement, Version 3.0*, TR E-171/ADA099054 (USA-CERL, March 1981).

[2] D. C. Hittle, R. E. O'Brien, and G. S. Percivall, *Analysis of Energy Conservation Alternatives For Standard Army Buildings*, TR E-183/ADA129963 (USA-CERL, March 1983).

*Note that applied retrofits vary with location of the building, but they are selected from a standard list for each building type.

reduce design and construction costs. It makes possible quantity procurements, interchangeability of parts, and the sharing of experience between installations. In addition, standardizing retrofits increases the quality of facility maintenance as product and system familiarity is increased.

The retrofit packages are envelope and system modifications which include such things as installing wall or ceiling insulation, replacing and/or blocking windows, partitioning areas of differing temperature, modifying air handling equipment, modifying boiler controls, replacing lights, etc. The retrofit packages for each building type were developed for five different climatic zones in the United States, since not all conservation alternatives were cost effective for all building categories or in all climatic regions.

Before applying energy conservation technology Army-wide, based on theoretical savings estimates, these technologies should first be demonstrated on a smaller scale. A demonstration program compares the theory to real world results, providing for more confident estimates of savings and feasibility before the huge capital investments required by an extensive retrofit program are made. This process verifies initial assumptions and recommendations. It also provides an opportunity to modify designs and adjust priorities in subsequent retrofits based on lessons learned in the initial applications.

Objective

The long-term objective of this project is to field test the energy conservation performance of theoretically-based retrofit packages when used on four standard building types. This report describes the retrofits and instrumentation, and discusses preliminary data.

Approach

1. TR E-183, *Analysis of Energy Conservation Alternatives for Standard Army Designs*, was reviewed to identify building categories and locations, building structural and mechanical layout, recommended retrofits, and expected energy and cost savings.

2. Four of the five standard designs reviewed in TR E-183 were selected for investigation: a vehicle repair shop, an L-shaped barracks, an enlisted personnel dining facility, and a rolling pin barracks.

3. Fort Carson, CO was selected as the site for the field test.

4. Final retrofit designs were made to accommodate site-specific constraints.

5. For each building type, one building was retrofitted and two or three identical but not retrofitted buildings were identified as reference buildings. A total of 14 buildings were chosen.

6. Metering equipment was installed in each building to record energy usage (British thermal units [Btus] for electricity, gas, and heated and chilled water) and building load (indoor and outdoor temperatures).

7. Energy use data from the 14 buildings has been collected for a side-by-side energy analysis.

8. Comparison of observed energy savings with expected savings has begun.

9. Detailed data analysis will be done and energy and cost effectiveness of the demonstrated packages will be determined.

Scope

This report details items 1 through 7 above and briefly reviews 8 and 9, which will be the subject of future work.

Organization of Report

Chapter 2 describes the impetus for the project, the expected improvements in energy and cost efficiency predicted in CERL report E-183, and the numerous benefits of the work effort. Chapter 3 describes the retrofit packages, including details of the demonstration site, each of the building categories, the retrofits theoretically suggested, the retrofits actually employed, and the qualitative insights gained in product selection and application. Chapter 4 describes the experimental procedure including an overview of the test-reference experiment; the determination, acquisition, and organization of the data set; the data cleanup strategy; and seasonal energy projection method. The initial data analysis, including direct energy comparisons, apparent energy savings, and insights on building operational trends are presented in Chapter 5. Chapter 6 discusses plans for future work efforts in interpreting the energy data, and Chapter 7 presents interim conclusions. Appendix A describes the hardware for energy monitoring and data acquisition, and Appendix B describes the computer software for data acquisition and analysis support.

Mode of Technology Transfer

It is anticipated that knowledge gained from this study will be included in FTAT notebook entries.

2 PROJECT BENEFITS

Anticipated Energy Reductions

The retrofit packages, produced from BLAST evaluations of various conservation alternatives (TR E-183), were developed to maximize the life-cycle payback on an energy-conservative investment. The Energy Conservation Investment Program (ECIP)[3] as of fiscal year (FY) 85 requires a savings to investment ratio (SIR) greater than one. All packages met the ECIP criteria, with initial calculations yielding sizeable estimates for energy savings.

BLAST runs were made for the standard buildings for five geographic sites* in different climatic zones. Table 1 summarizes the predictions of all-site average energy consumptions and savings. These predictions apply for any of the five geographic sites. The total anticipated energy savings was estimated at 2×10^{12} Btus/yr for Army-wide implementation of the suggested retrofits for the four building types.

Other Benefits

The savings from Table 1 were estimated from the retrofits' anticipated reduction of building energy requirements. However, less tangible effects that have occurred and that also represent savings, include decreased maintenance, enhanced appearance, improved functioning, greater comfort, and raised occupant morale.

Table 1

Summary of Predicting Savings from Retrofit

Building Type	Energy Consumption Btu/sq ft/yr (kWh/m^2/yr) Before		After		Percent Reduction
Motor repair shop	417	(1314)	272	(857)	35
Type 64 barracks	222	(699)	131	(413)	41
Mess hall	492	(1550)	295	(929)	40
Rolling pin barracks	172	(534)	117	(368)	32

(Source: D. C. Hittle, R. E. O'Brien, and G. S. Percivall, *Analysis of Energy Conservation Alternatives for Standard Army Buildings*, TR E-183 [USA-CERL, March 1983].)

[3]Energy Conservation Investment Program (ECIP) Guidance, multiple-address letter from the Office of the Chief of Engineers (4 March 1985).

*Colorado Springs, CO; Columbia, MO; Raleigh, NC; Phoenix, AZ, and Fort Worth, TX.

Additionally, many benefits arise just from the demonstration, regardless of the energy outcome. These include:

- Determination if current retrofit packages are cost effective prior to wide-scale implementation

- Insight into steps necessary to make retrofit packages cost effective if they do not meet expectations

- Insight into the current energy use patterns at the monitored buildings

- Information on practical concerns in applying computer-optimized retrofit packages

- Insight into the effects of a highly variable baseline in a test-reference energy study

- Development of data acquisition and data management skills in the research community

- Improved (although perhaps not optimized) energy efficiency in four buildings at Fort Carson, CO with retrofits of insulation, updated controls, new windows, etc.

- Installation of electric and gas meters for future energy monitoring of the test buildings.

3 THE RETROFITS

Demonstration Site

Fort Carson, CO was chosen as the demonstration site. Fort Carson is situated south of Colorado Springs in east central Colorado. Its location is 38°41' N latitude, 104°46' W longitude. Its elevation is 5840 ft. Annual heating degree days are 6373 (base 65). Annual cooling degree days are 692 (base 65).[4] It is an advantageous location for many reasons. Fort Carson has four of the five building categories originally studied. This limits travel, administration, and field support requirements to one site. It is geographically near Colorado Springs, one of the representative weather locations in the BLAST studies. Hence energy comparisons of measured data with BLAST data require less weather compensation. And finally, Fort Carson has a substantial heating requirement. This makes energy consumption totals sufficiently large that they are less skewed by errors in simplifying assumptions than smaller energy totals would be.

Building Categories

Building Overview: Motor Vehicle Repair Shops

Figures 1 and 2 show a floor plan and an exterior view of the motor vehicle repair shop, respectively. The motor repair shop is a single-story rectangular structure with a floor area of 4800 sq ft and window area of 1278 sq ft. One end of the building has a fenced-in, secured area for an office and tools/parts storage. The rest of the building consists of high-bay vehicle work stations. Building walls are constructed of concrete blocks. Heating is provided by suspended steam unit heaters serviced by a steam boiler located in the mechanical room at the end of the building. Average baseline energy consumption for the motor repair shop was estimated at 2002 MBtu/yr. The retrofits proposed (see Table 2 and "Retrofit Details: Motor Vehicle Repair Shops") were expected to reduce this annual consumption by 35 percent.

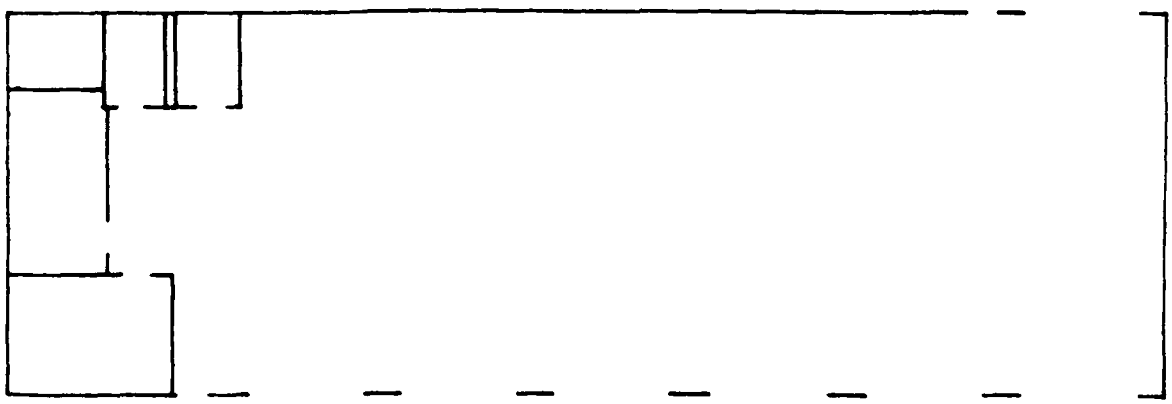

Figure 1. Floor plan: motor vehicle repair shop.

[4] *Engineering Weather Data*, Air Force Manual (AFM) 88-29, Army Technical Manual (TM) 5-785, Naval Facilities Engineering Command Publication (NAVFAC) P-89. (Departments of the Air Force, the Army, and the Navy, 1 July 1978.)

Figure 2. Exterior view: motor vehicle repair shop.

Table 2

Retrofit Package: Motor Vehicle Repair Shop (Bldg 633)

New programmable thermostats	Existing thermostats were replaced by Johnson Controls programmable thermostats which will allow night set back temperatures and differing temperatures between the office and shop areas.
New boiler controller	Existing boiler controller was replaced by a Johnson remote temperature controller which is based on outside air temperature.
Office partition	The office area was partitioned off from the shop area by replacing the existing chain-link fence with an insulated stud wall partition.
New overhead doors	Existing overhead doors were replaced by Clopay Corp. insulated doors which will reduce air infiltration around door edges and heat conduction through the doors.
Insulating window area	New metal panels from Alliance Wall were installed inside the existing glazing on approximately 50 percent of the window area. The panels are backed by a stud wall with batt insulation and gypsum board finish.
Interior wall insulation	Interior walls were overlaid with 3-1/2 in. (R-11) batt insulation installed between stud furring and covered by gypsum board.

Building Overview: L-Shaped Barracks

Figures 3 and 4 show a floor plan and an exterior view for the L-shaped (Type 64) barracks. The L-shaped barracks is a three-story building with an adjoining single-story mess hall area which has a total floor area of about 38,000 sq ft. There are 12,946 sq ft of concrete block exterior wall and 4965 sq ft of glass. Heating is provided by a hot water system which is serviced by two steam boilers located in the mechanical room of the building. Cooling is provided by a chilled water system which is serviced from a central plant. Average baseline energy consumption for the L-shaped barracks was estimated at 8346 million Btu/yr. The retrofits proposed (see Table 3 and "Retrofit Details: L-Shaped Barracks") were expected to produce a 41 percent reduction in this annual consumption.

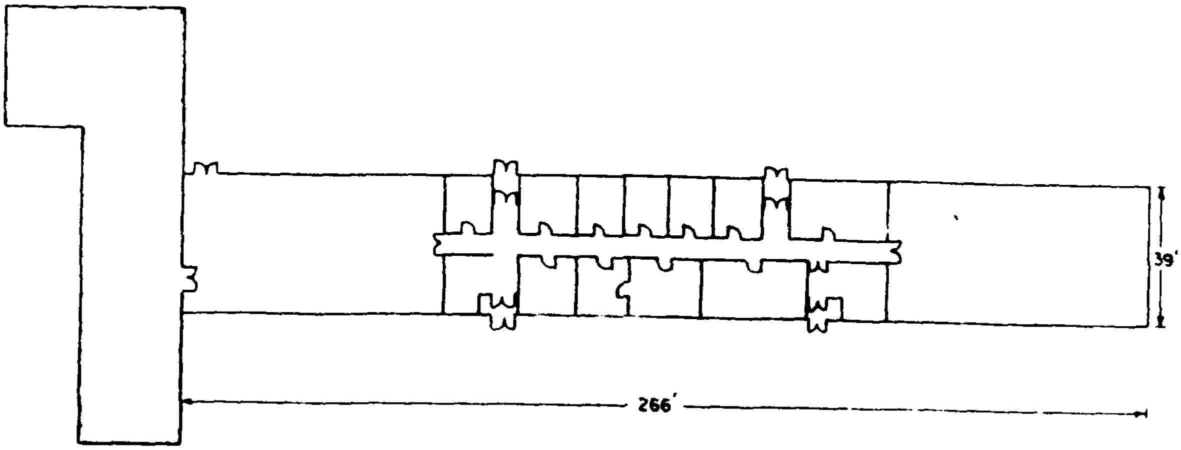

Figure 3. Floor plan: L-shaped barracks.

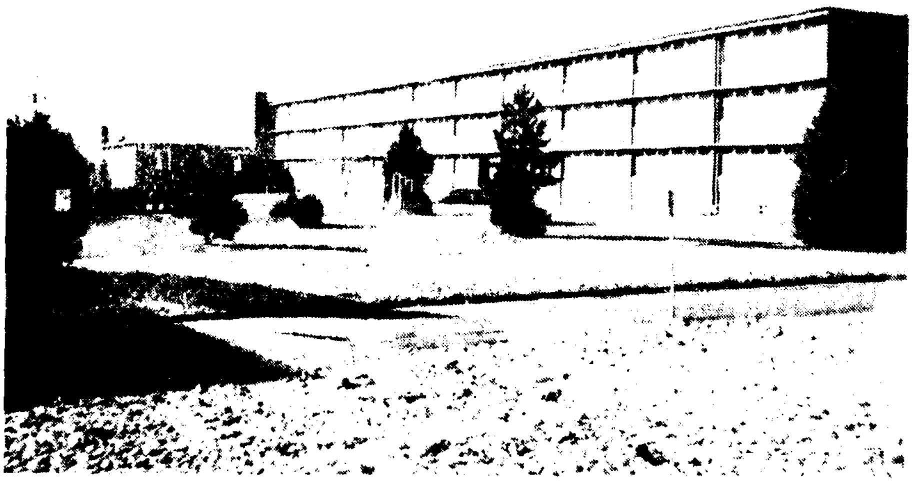

Figure 4. Exterior view: L-shaped barracks.

Table 3

Retrofit Package: L-Shaped Barracks (Bldg 811)

Replace window units	A total of 259 existing window units were replaced with Alenco double-glazed, double-hung, thermal-type window units. The general pattern for window replacement is shown in Figure 5. (The new units are narrower than the existing units, so the vacated space was blocked up.)
Block window area	All area between the newly installed windows was filled with concrete masonry units. Blocking reduced the window area by approximately 50 percent. (The typical blocking pattern is shown in Figure 5.)
Minimize outside air intake at AHUs	The air intake dampers of two existing air handling units (AHUs), which serve the (unused) kitchen area and an adjacent common area, were modified to recirculate in-building air instead of bringing in outside air for conditioning.
New HW heating system controller	A new heating system controller, from Taylor, was installed to more precisely control the temperature of the circulating hot water (HW) according to the outside air temperature. The water temperature was adjusted (linearly) between 190 and 100 $^{\circ}$F as the outside air varies from 0 to 65 $^{\circ}$F. The control system was replaced due to its technological and chronological age.
Exterior insulation	The exterior insulation system, from Insulcrete, consists of 2-in.-thick rigid foam insulation and a nylon mesh material (3/8-in. mesh pattern) which is mechanically fastened to the exterior of the concrete block wall. The insulation and mesh are covered by a concrete coating (1/4-in. thick) and a stucco finish coat (1/8-in. thick). The insulation system covers the entire exterior (vertical) surface of the building.

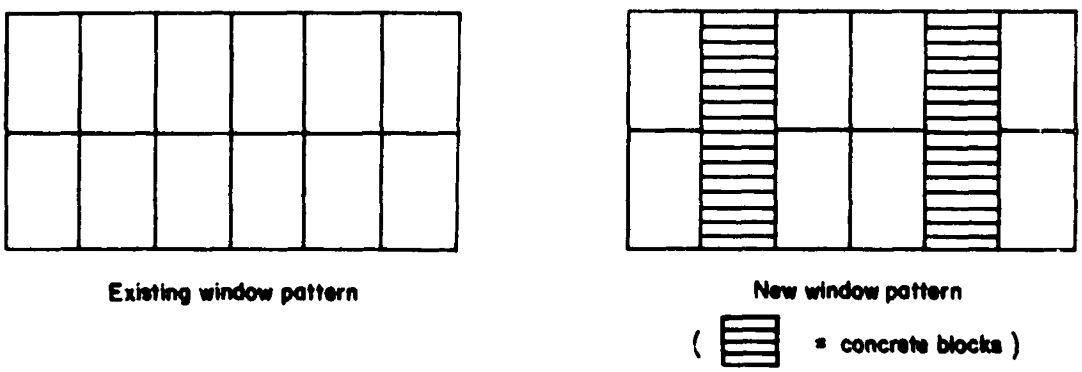

Figure 5. Existing and new window pattern: L-shaped barracks.

Building Overview: Dining Hall

Figures 6 and 7 show a floor plan and an exterior view for the dining hall. The enlisted personnel mess hall is a one-story structure with an attic, kitchen, dining room, and a combined cloak room and entranceway. The total floor area is 10,620 sq ft. Walls are constructed of brick and concrete masonry units. The domestic hot water system and heating systems are serviced from a central plant. Average baseline energy consumption for the enlisted personnel mess hall was estimated at 5225 million Btu/yr. The retrofits proposed (see Table 4 and "Retrofit Details: Dining Hall") were expected to produce a 40 percent reduction in this annual consumption.

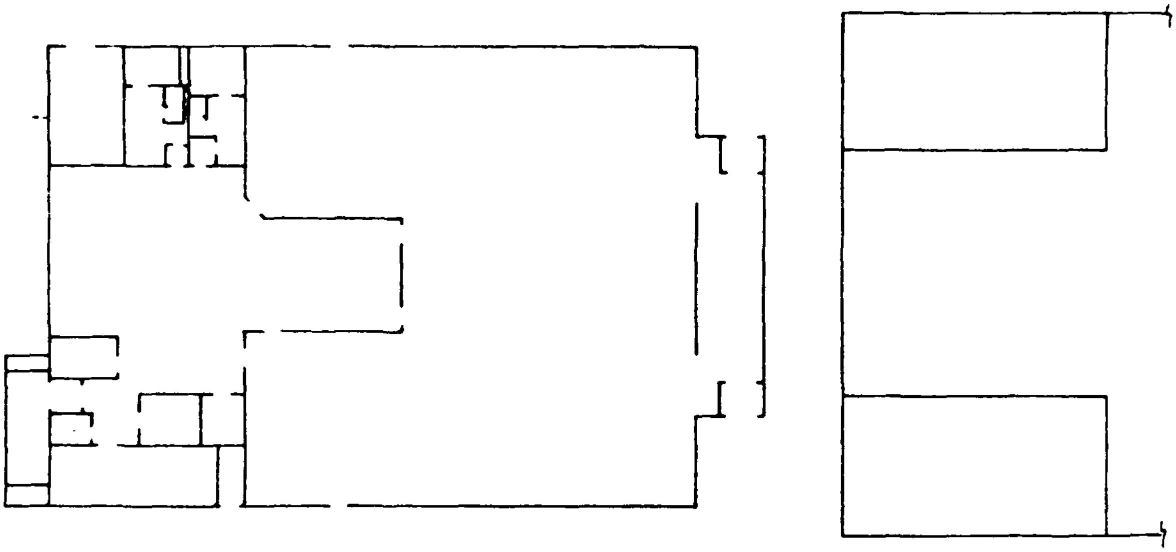

Figure 6. Floor plan: dining hall.

Figure 7. Exterior view: dining hall.

Table 4

Retrofit Package: Dining Hall (Bldg 1361)

Programmable thermostats	Three existing thermostats were replaced with Johnson Controls programmable thermostats which permit programming for night setback temperatures. Additionally, a seven-day clock was installed to enable weekend temperature setback.
Kitchen hood ventilating system	The existing kitchen hood ventilating system was replaced with a "short-circuiting" type ventilating hood which reduces the amount of conditioned air that is exhausted from the building space during hood operation.
HW temperature reset controller	A new heating system controller from Taylor was installed to more precisely control the temperature of the circulating hot water (HW) according to the outside air temperature. The water was adjusted (linearly) between 180 and 100 °F as the outside temperature varies from 0 to 65 °F. The existing system was replaced due to its technological and chronological age.
Incandescent lights	Five fluorescent lighting fixtures replaced existing incandescent fixtures (in the foyers and kitchen area).
Insulating panels over 50 percent of windows	Alliance Wall insulated metal panels were installed over 120 sq ft of window area. Twenty-four sq ft of existing metal panels had already received a backing of insulation installed between furring channels and covered by gypsum board.
Ceiling insulation	The entire ceiling area had already received 6-in. (R-19) batt insulation panels above each ceiling tile panel.
Entrance doors	Both sets of doors at both entrance foyers were replaced by American Standard steel doors to reduce air infiltration.

Building Overview: Rolling Pin Barracks

Figures 8 and 9 show a floor plan and an exterior view of the rolling pin barracks, a three-story building with 40,698 sq ft of floor area. The exterior walls are brick and concrete block. There are 16,061 sq ft of exterior wall and 4399 sq ft of glass. Heated and chilled water are supplied from a central plant for building heating, cooling, and domestic hot water. Average baseline energy consumption for the rolling pin barracks was estimated at 7000 million Btu/yr. The retrofits proposed (see Table 5 and "Retrofit Details: Rolling Pin Barracks") were expected to produce a 32 percent reduction in this annual consumption.

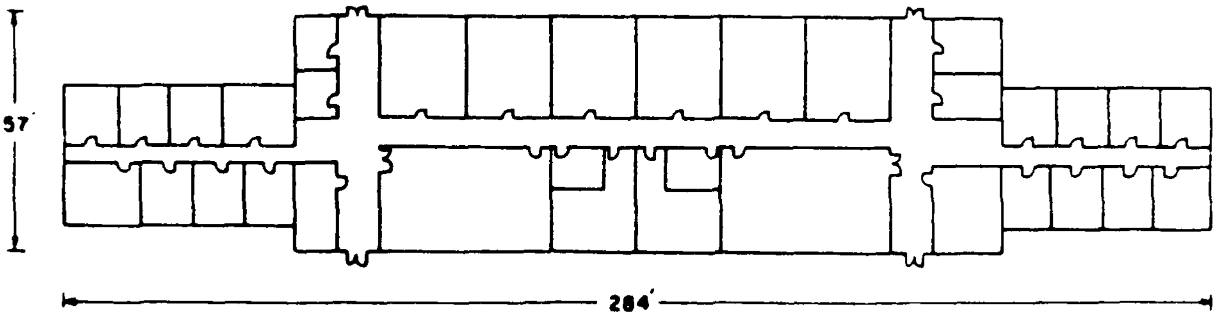

Figure 8. Floor plan: rolling pin barracks.

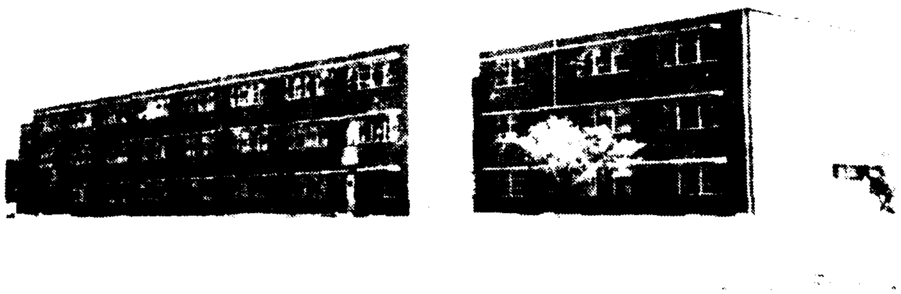

Figure 9. Exterior view: rolling pin barracks.

Table 5

Retrofit Package: Rolling Pin Barracks (Bldg 1363)

New window units	All of the existing 286 window units were replaced with Alenco double-glazed, thermal-type window units.
Heating system controller	A new Taylor heating system controller was installed to more precisely control the temperature of the circulating hot water according to the outside air temperature. The water temperature is adjusted (linearly) between 200 and 140 °F as the outside air varies from 0 to 65 °F. The control system was replaced due to its technological and chronological age.
Low leakage dampers for intake air	Two 3 ft by 9 ft existing intake air dampers were replaced with Barber Coleman low leakage dampers.

Retrofit Package Details

Tables 2 through 5 listed the implemented retrofit packages. This section comments on the application of these packages for items where the tables are not self-explanatory. It discusses the energy conservation alternatives employed (including reasons for the changes made from initial recommendations made in TR E-183), and observations on how the implemented retrofits are functioning. The proposed packages were changed to accommodate site constraints which were not anticipated during initial design. Meetings and informal visits with site personnel before and after retrofit changes have shed light on retrofit functioning and acceptability.

References to manufacturers in the following sections are included to assist users in locating particular products. They should not be interpreted as specific product endorsements. There are many manufacturers who supply similar, suitable products.

Retrofit Details: Motor Vehicle Repair Shops

Thermostats. The programmable thermostats allow comfort conditions in two areas which have different heating requirements. However, the night setback options were disabled by base personnel after installation (possibly due to unanticipated night work and/or confusion about programming procedures). It may be appropriate to post sample thermostat programs on the wall or to prevent access by unauthorized personnel.

Boiler Controller. The new remote-temperature boiler controller shuts off the boiler when the outside air temperature rises above a setpoint. This eliminates the need to turn off the boiler for the summer and restart it in the fall, and it ensures that heat is produced during the winter only when there are appropriate conditions.

Office Area Partition. This retrofit has been met with great enthusiasm by the occupants who can now work at their desks in warmer conditions than can be maintained in the bay area. This also provides bay area workers with a warm refuge after extended work periods. These comfort considerations have prompted the occupants of nearby shops to employ this or similar modifications to their buildings, even though the energy savings have not been verified.

Overhead Doors. One of the seven doors installed has had a problem with the spring mechanism which eases the lowering of the door, and it has needed repeated attention. However, most of the new doors work quite satisfactorily.

In addition to the increased insulative value of the doors, the fact that they are new is a further benefit because all panels are intact (in contrast to the numerous holes and makeshift repairs in the existing doors) and the doors open and close easily, which makes the workers more likely to close them in cooler weather. The original plans had called for weather stripping around the doors rather than replacing them but the generally poor condition of the existing doors led to the replacement decision.

Windows and Walls. The comfort level in the shop area has increased greatly due to the modifications to the doors, windows, and walls. Now workers can work for longer stretches without requiring a warming break and can work without gloves on jobs which benefit from increased manual dexterity.

Retrofit Details: L-Shaped Barracks

Walls. The appearance of the barracks building with the new stucco finish has been dramatically improved over the painted concrete blocks of the existing units, prompting inhabitants of other barracks to request the same facelift. Additionally, the maintenance requirements should be lessened as exterior painting will be limited to trim work.

Ventilation. Natural air infiltration into the building is assumed sufficient to meet ASHRAE fresh air requirements.[5]

Controls. Taylor proportional and proportional-integral pneumatic heating system controllers were installed in an effort to more precisely control the temperature of the circulating heating hot water according to the outside air temperature. The heating requirements of a building are decreased as the outdoor temperature increases and so the temperature of the hot water supplied to the radiators does not need to be as high. The converse is true as outdoor temperatures get colder. Resetting the temperature of the heating hot water with changes in the outdoor temperature is more energy conservative than supplying water at a constant temperature.

The existing control system was designed to maintain a constant hot water supply temperature regardless of outside temperature. It consisted of a selectable setpoint aquastat in the heating hot water supply line which modulated the steam valve at the hot water converters. The replacement controllers allowed for the resetting of the heating hot water supply temperature. However, they did not control the temperature of the hot water as precisely as had been hoped. Reasons for this may include drift of controller calibration, complicated controller settings and adjustments, and inappropriately sized steam valves. Plans for future attempts at better control include less complicated reset controls and more appropriately sized steam valves servicing the hot water converters.

Retrofit Details: Dining Hall

Kitchen Hood. The proposed retrofit plan called for a heat recovery system for the exhaust air from the kitchen hoods which would transfer heat from exiting air to incoming ventilation air. However, when final designs were under way it was discovered that the size of the heat exchanger required would be impractically large. A large heat exchanger was necessary due to the low temperature of the exiting air and the sufficiently high air velocity which needed to be maintained to entrain particles of grease.

An alternate plan replaced the existing hood with a "short-circuiting" ventilating hood. In this system outside air is brought into the building and then redirected back up the flue and mixed with odor-filled inside air. In this way the necessary air flow through the hood is achieved while reducing the amount of conditioned air that is exhausted from the building space during hood operation.

Because all the outside air which is brought into the building does not make a direct path up the flue, a Reznor gas-fired, make-up air heater was installed which moderately heats the outside air to prevent frigid drafts in the kitchen area.

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[5] *ASHRAE Handbook 1985 Fundamentals* (American Society of Heating, Refrigerating and Air-Conditioning Engineers [ASHRAE], Atlanta, 1985), Chapter 22.

Ceiling Insulation. The original plan called for the entire ceiling area to receive 6 in. (R-19) batt insulation panels above each ceiling tile panel. However, the demonstration building had received ceiling insulation of this amount prior to this experiment.

Entrance Doors. Existing doors were loosely fitting and in poor condition.

Retrofit Details: Rolling Pin Barracks

Windows. Original plans for this barracks, and the L-shaped barracks as well, had called for nonoperable storm windows instead of new window units. Nonoperable windows were understandably unacceptable to the site considering the inadequate state of comfort control in the buildings and the very relative definitions of comfort which arise when people from diverse geographic areas live together at one site. Double-glazed thermal sash windows were agreed upon as an acceptable energy conservation alternative. The cost of these windows is substantially higher than the originally planned storm windows though and will need to be carefully reviewed in terms of acceptable payback. Triple-track, interior-operable windows may have been a viable alternative and should be considered for future retrofits of this sort.

Walls. Original plans called for the exterior walls to receive foamed-in-place insulation in the cavity between the block and the brick facia. This retrofit was not employed due to several hindrances. One concern was the uncertain expansion of the foam in the irregular cavity which was discovered. The walls had accommodated numerous holes which had not been accounted for and which would not contain the foam but rather would allow it to ooze out onto the wall surfaces. The uncertain expansion could also dislodge bricks from the outside wall.

Cavity access was also a concern. It had been anticipated that the foam would be installed while the window units were removed and that a 1-1/2 in. opening on the sides of the window holes would allow cavity access. When the windows were removed it was discovered that the bricks had been turned sideways at the window holes. This left a 1/2-in. wide access which was mortared shut, and which was not large enough to accommodate the foam equipment. One final concern was the uncertainty about the building drainage which may have been taking place in that cavity. These collective concerns led to the dismissal of this retrofit.

An option which may be a viable alternative and should be considered in the future would be filling the cavity with vermiculite. It can be blown in, it will not expand uncontrollably, and it will not be damaged by water.

Summary

The design, implementation, and use of the retrofit packages has resulted in important lessons learned in product selection and application. These lessons have identified some of the steps necessary to bring about acceptable, effective retrofits in existing standard Army buildings.

Product use poses many challenges. A retrofit selection needs to be based on more than just energy considerations. The following list of additional considerations is based on the efforts to date.

- A retrofit measure needs to be acceptable to the building users and maintainers.

- A retrofit will have little or no effect if building occupants disable or bypass it.

- The installed product must function as expected.

- A retrofit should be practical and doable.

- A retrofit must work within the physical constraints of a system.

- Potential side effects of a retrofit need to be reviewed.

The nonenergy-related benefits of a retrofit can be substantial and deserve recognition. Improvements in building comfort and appearance, occupant morale and productivity, product functioning, and maintenance requirements were noted at Fort Carson.

Figures 10 through 29 show various aspects of the retrofits. Most of them are "before" and "after" photographs of the same area. Exceptions are the full-building shots (Figures 10, 17, and 23), which should be compared to the appropriate "before" exterior view (Figure 2, 4, or 7), and the pictures of the old and new controls and dampers (Figures 22, 26, and 29), which are very similar in all the buildings fitted with new controls.

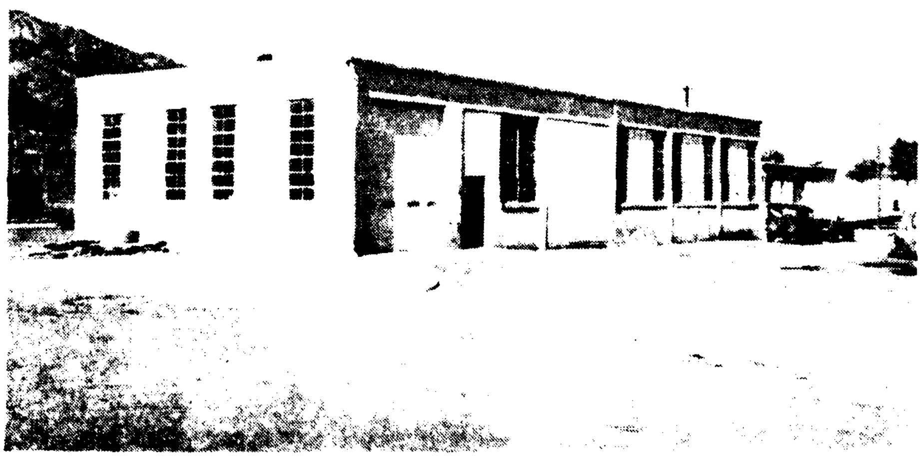

Figure 10. Retrofitted motor shop with new door and new window panels.

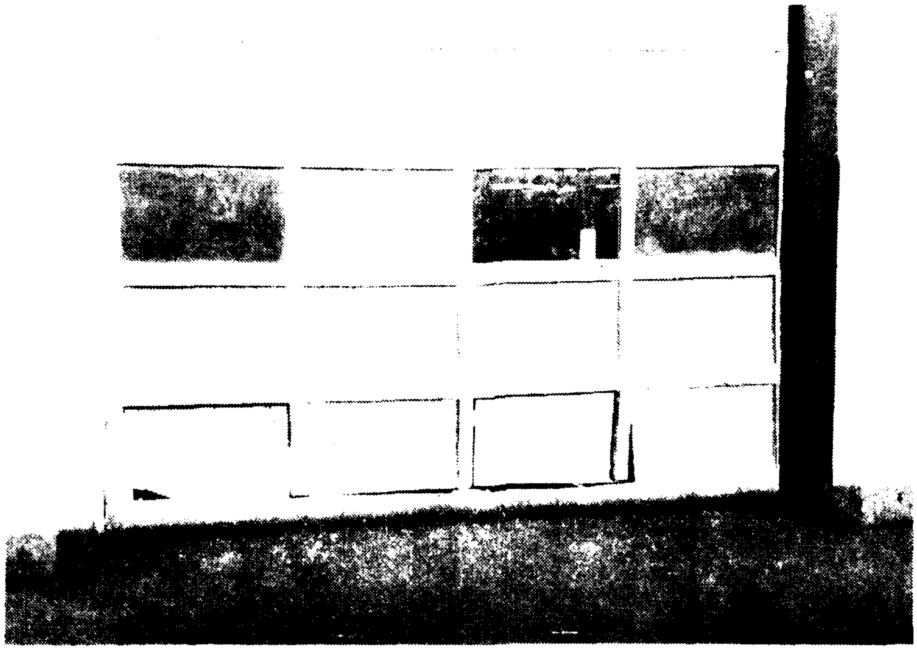

Figure 11. Old bay doors of motor shop.

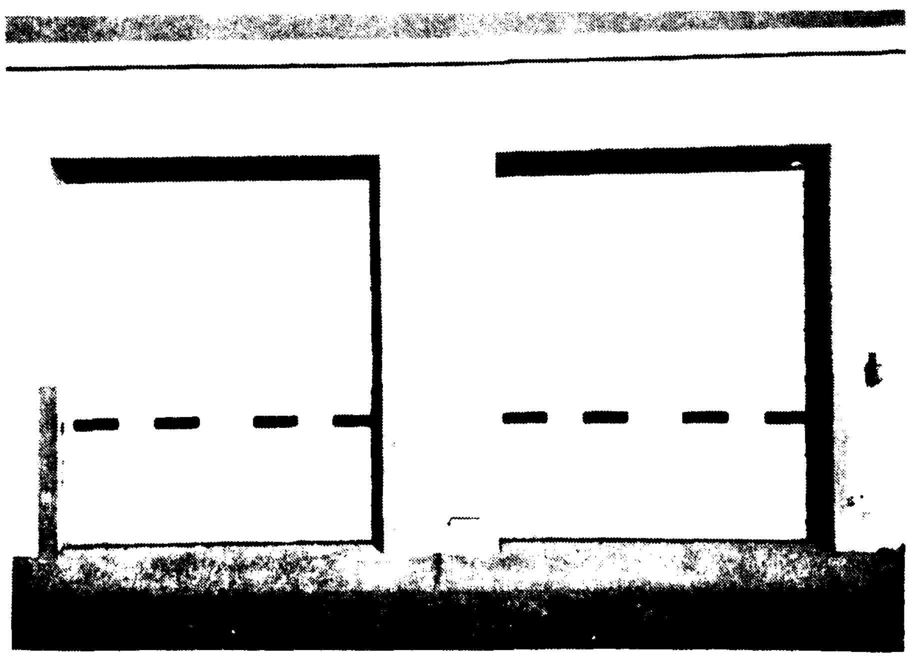

Figure 12. New bay doors of motor shop.

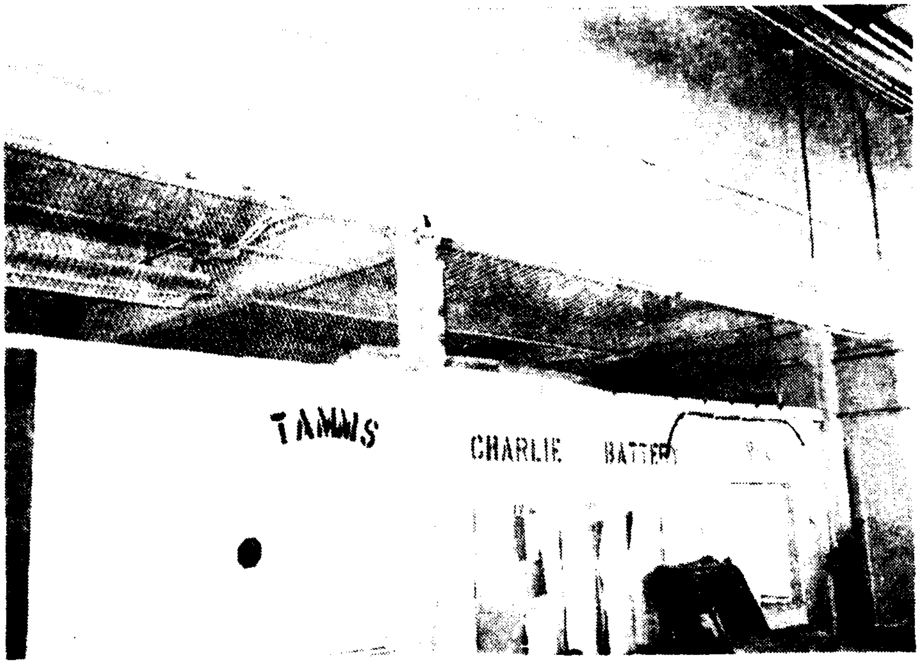

Figure 13. Old fence between office and bay area of motor shop.

Figure 14. New wall partition between office and bay area of motor shop, replacing fence.

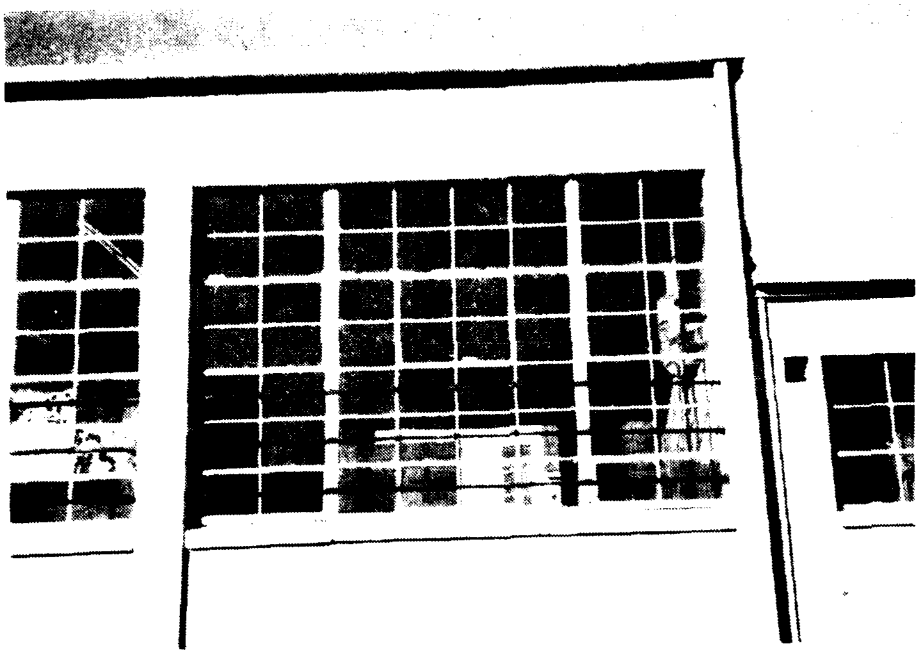

Figure 15. Old windows of motor shop.

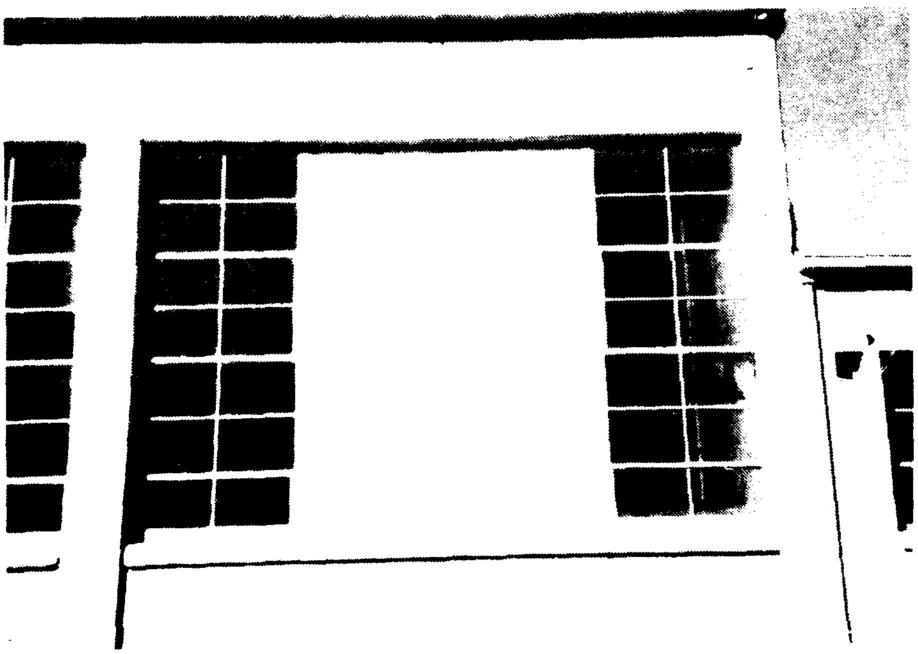

Figure 16. New insulated windows of motor shop.

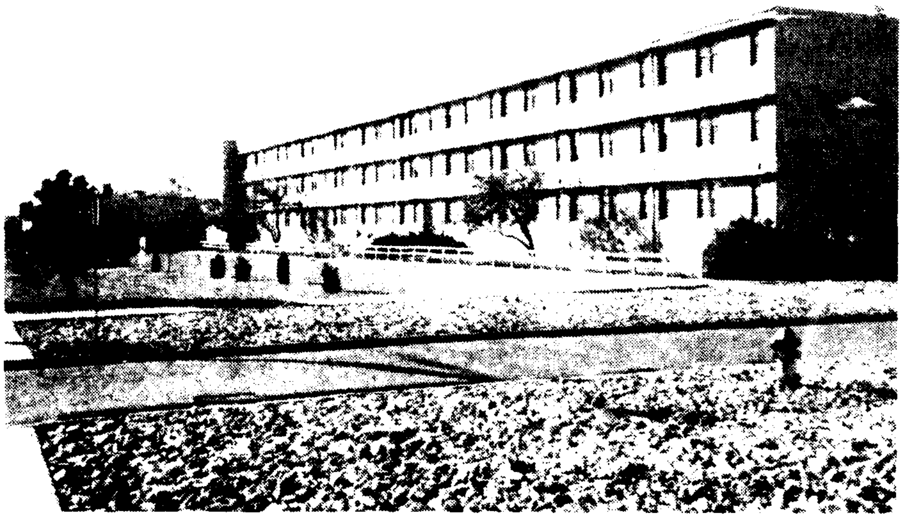

Figure 17. Exterior view of retrofitted L-shaped barracks, showing reduced window area.

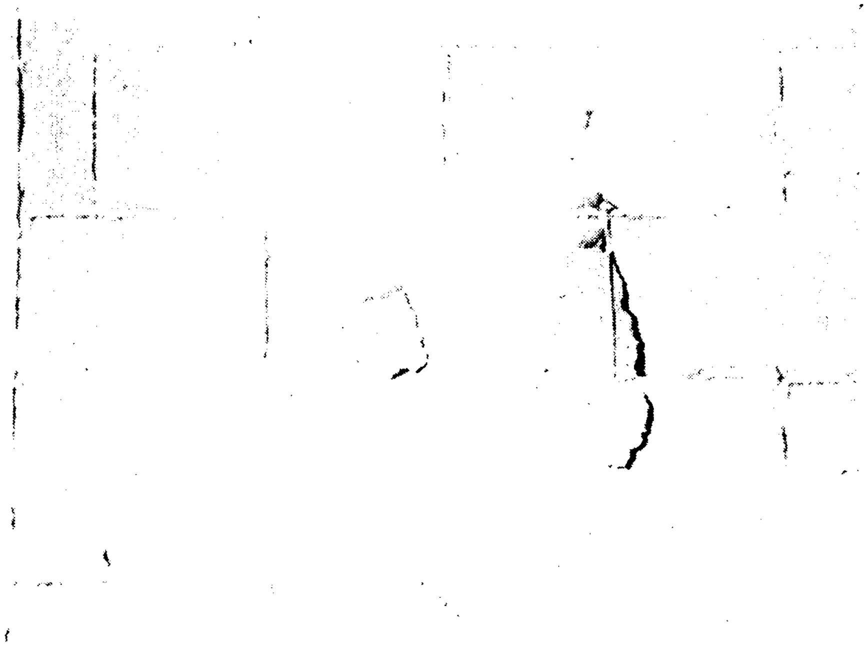

Figure 18. Old masonry wall of L-shaped barracks.

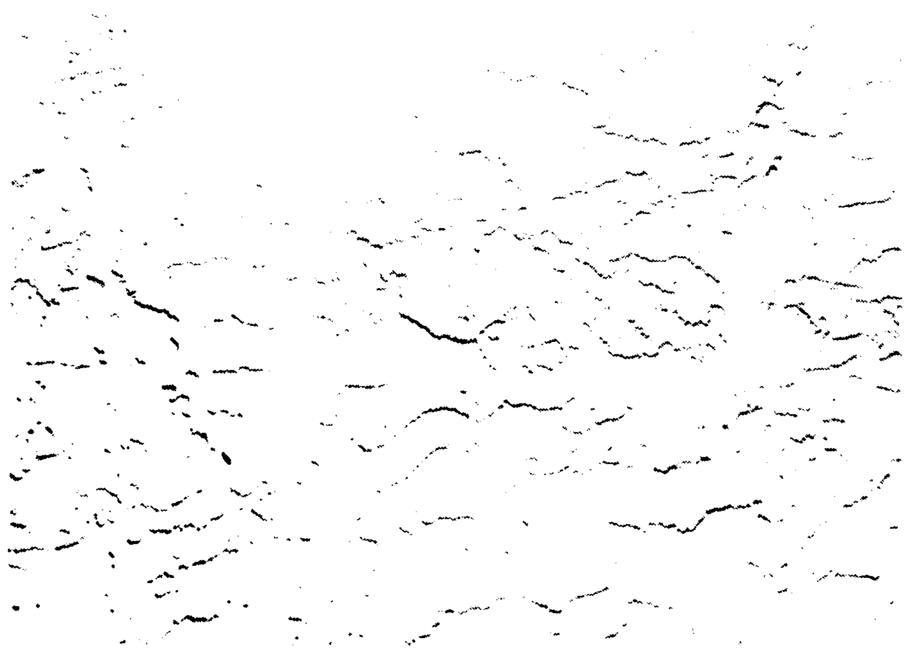

Figure 19. New stucco wall of L-shaped barracks.

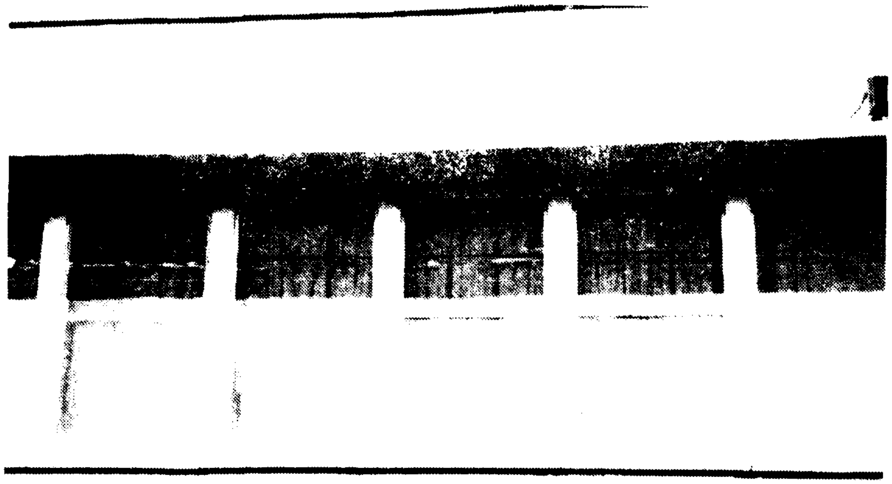

Figure 20. Old windows of L-shaped barracks.

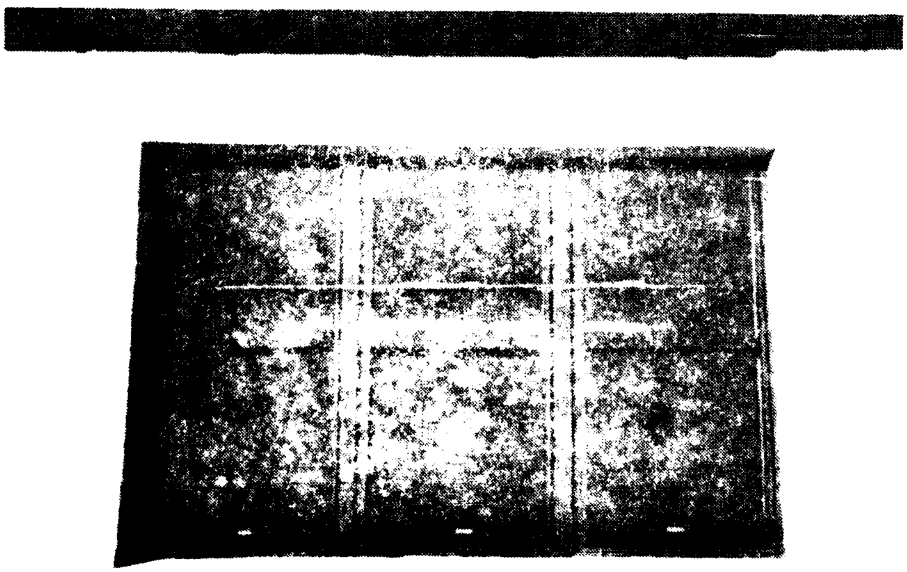

Figure 21. New windows of L-shaped barracks.

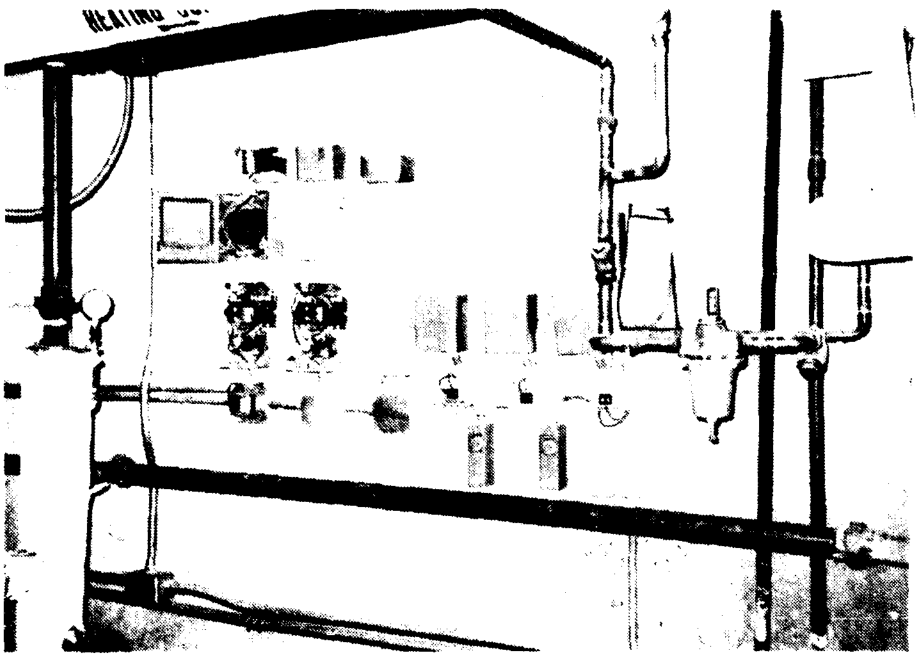

Figure 22. Old electric controllers of L-shaped barracks.

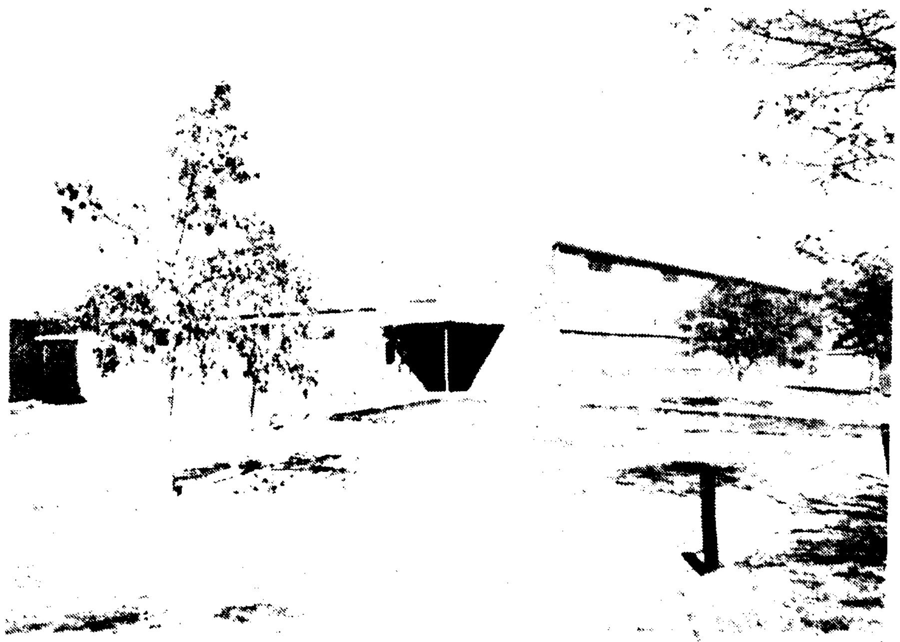

Figure 23. Exterior view of retrofitted dining hall, showing new door and reduced window area.

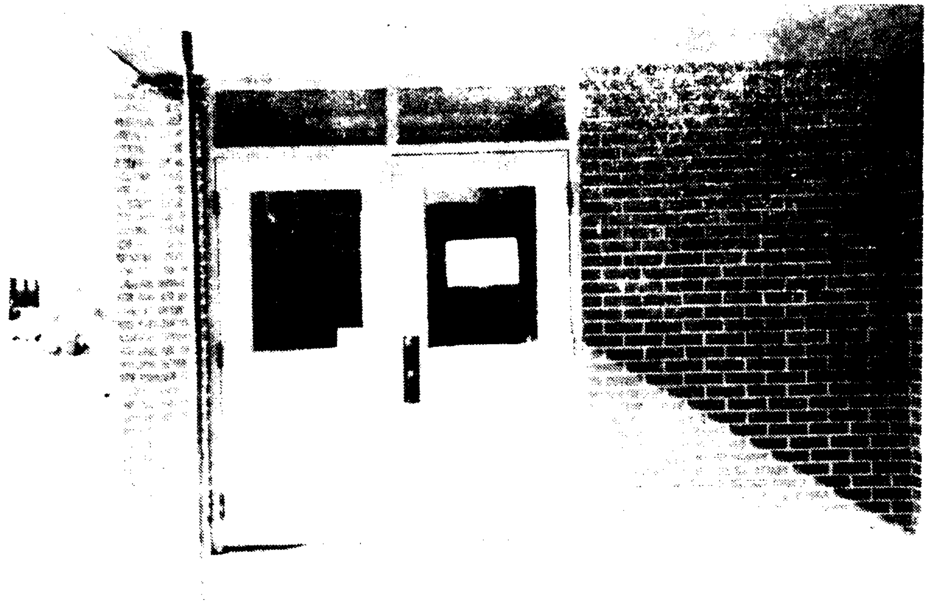

Figure 24. New exterior doors of dining hall.

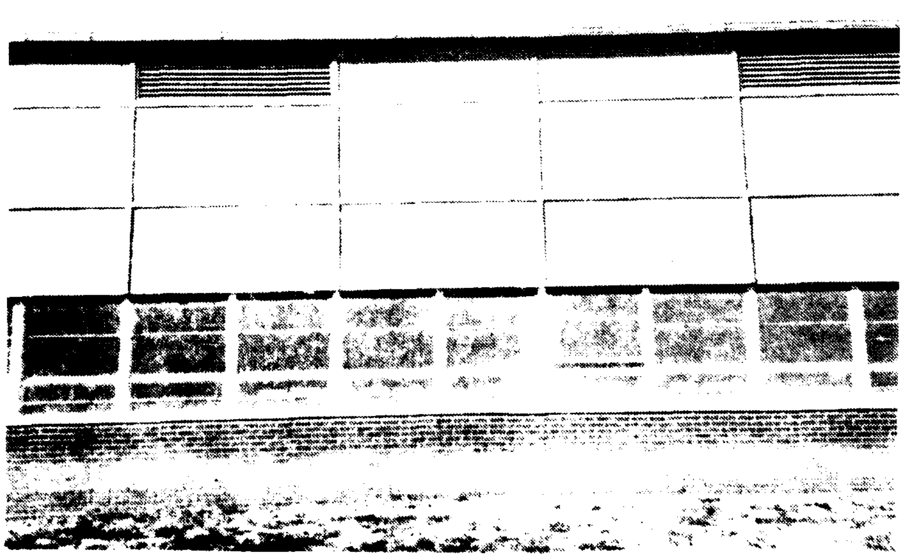

Figure 25. New window panels of dining hall.

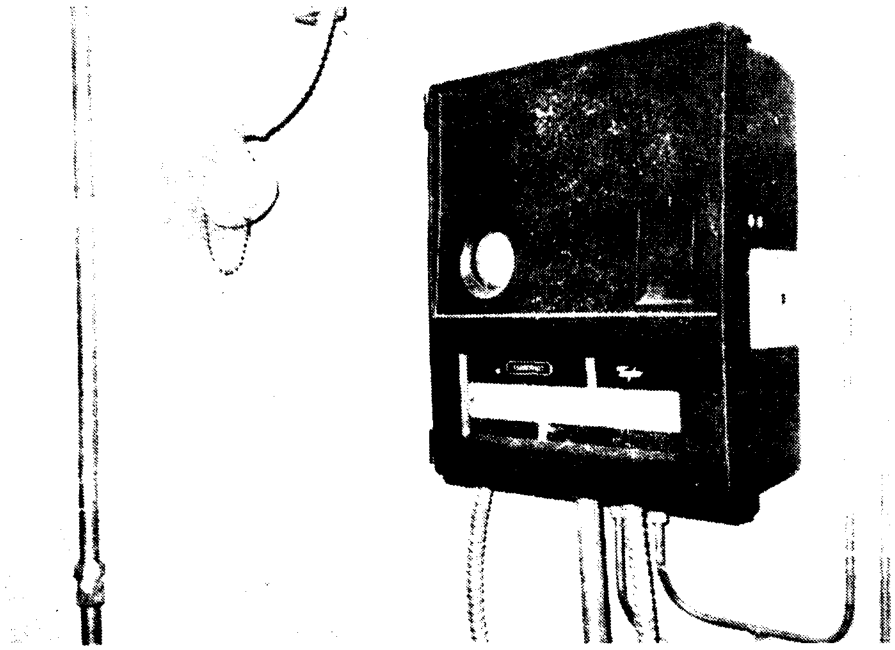

Figure 26. New pneumatic reset controllers (with outside air RTD) of dining hall.

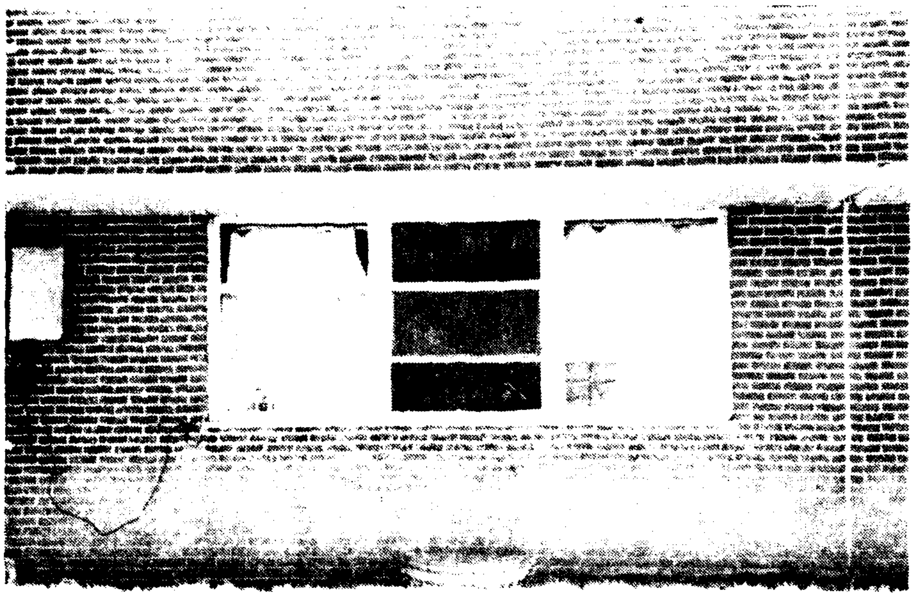

Figure 27. Old windows of rolling pin barracks.

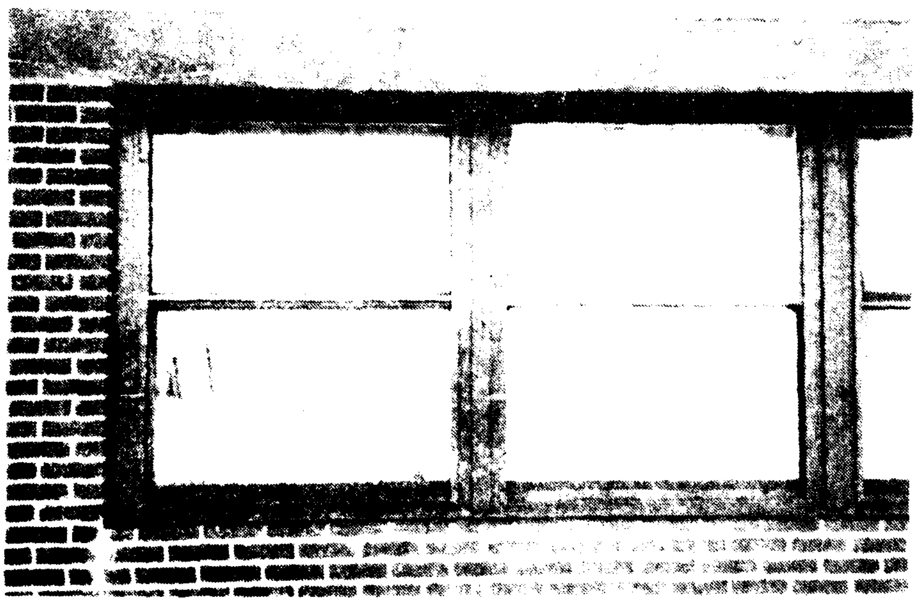

Figure 28. New windows of rolling pin barracks.

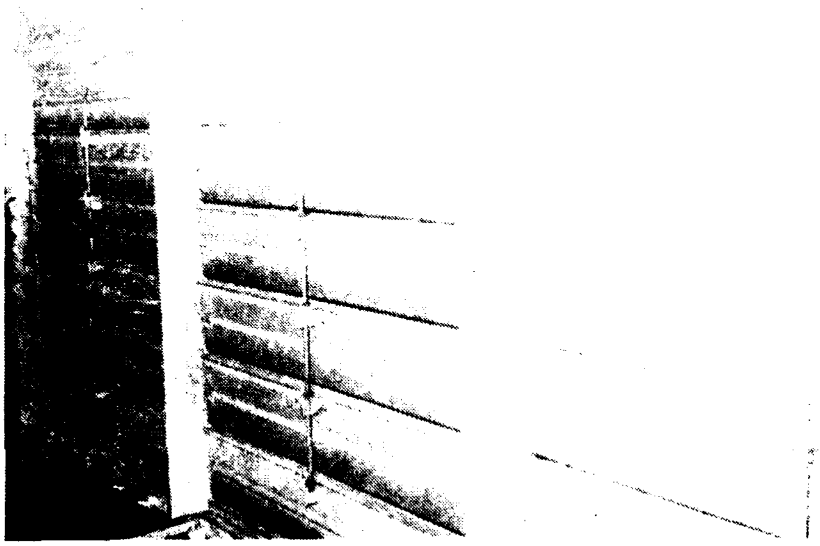

Figure 29. Old ventilation dampers of rolling pin barracks.

4 PROCEDURE

Overview of the Test-Reference Experiment

A test-reference experiment was set up for each of the four building categories. In each group one building at Fort Carson was identified to receive the retrofit package (the test building) and twc or three identical but not retrofitted buildings, also at Fort Carson, were identified as reference buildings. A list of the buildings numbers for each experiment is given in Table 6. Energy use data was gathered simultaneously from the buildings for the side-by-side energy comparison. The difference between test building consumption and average reference building consumption is assumed to be due to the effect of the retrofit package. No weather corrections are necessary for the energy comparisons since all buildings experienced the same weather conditions.

Ideally, test-reference building experiments[6] should include a calibration phase consisting of several years of collecting energy data on all buildings prior to retrofit measures. This would allow the determination of steady state consumption differences between the test and reference buildings (which are the result of differences in structures or mechanical equipment) which would distort a direct energy comparison. This before-retrofit difference would then be used to adjust direct energy comparisons during the comparison phase. The comparison phase would ideally also be a multiyear effort and would perhaps involve several test buildings. However, the financial and time requirements of such an effort made it impracticable for the current project, which is limited to side-by-side data from a modest-sized sample.

To minimize the error in the test-reference assumption, i.e., that the buildings are identical in all respects except the retrofit, care was taken to select the buildings most nearly identical. The buildings chosen have the same:

- Location (Fort Carson)
- Year of construction

Table 6

Building Numbers for Each Experiment

Building Category	Test Building	Reference Buildings
Motor Repair Shop	633	634, 635, 636
L-Shaped Barracks	811	812, 813
Dining Hall	1361	1369, 1669
Rolling Pin Barracks	1363	1663, 1666, 1667

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[6]Gian Vincenzo Fracastro and Mats Douglas Lyberg, *Guiding Principles Concerning Design of Experiments, Instrumentation and Measuring Techniques* (Swedish Council for Building Research, 1983), Chapter IId.

- Construction materials
- Layout
- Heat plants and distribution systems (or very similar)
- Orientation (or very similar)
- Weather conditions (neglecting localized shading and wind variations), since metering was simultaneous and the buildings are close together.

Additionally, at least two reference buildings were chosen for each category. This experimental setup allows for a good estimate of the effect of a retrofit package. The method does, however, force an estimate of energy savings due solely to retrofit changes. Alternately, it assumes that the retrofit packages are the major (or only) cause of changes in building energy consumption. This is inherent in the method since each building is evaluated as a complete, integrated system. Nevertheless, the method does provide a case demonstration of achievable savings in the real world.

The retrofit package, as well as other important factors such as occupant behavior, control system settings, mechanical equipment efficiencies, etc., affect the gathered data. The interactions of these influences create a building energy consumption which is not equal to the sum of the individual factors acting alone. This synergism of overlapping energy consumption factors is captured in the gathered field data. Since the integrated system determines the cost of building usage and the resultant cost savings justify the retrofit expense, the estimates of energy savings from real world investigation are quite valuable.

Determination and Acquisition of the Data Set

A data set was identified to allow monitoring of total building energy use, component (heating, cooling, electricity) energy use, and building load (indoor/outdoor temperatures). This data set allows comparison of energy performance between buildings and with the initial energy calculations, and it provides some insight on operational conditions.

To this end, TR E-183 was reviewed to identify expected space conditioning systems for each building category. Additionally, the architectural and mechanical blueprints for the buildings were obtained from the Directorate of Engineering and Housing at Fort Carson. These prints were studied to determine actual energy consuming systems employed at the site. A combination of air, water, and steam heating, ventilating, and air-conditioning (HVAC) systems were found. In some cases the sytems at Fort Carson were different from those modeled in TR E-183. A site inspection was conducted to verify as-built conditions and identify appropriate metering locations.

Metering equipment was selected to measure component energy usage. Total building consumption is determined as a sum of these components. All 14 buildings were outfitted with instruments and data acquisition and recording equipment. These instruments monitor flow and temperature of heated and chilled water; measure indoor and outdoor temperature; and meter domestic hot water, steam table condensate, natural gas, and electric usage. Time and date information, integrated Btu calculations, and selected statistical functions are also logged, in addition to signals from the above sensors.

All measurements are digitally recorded in battery-protected random access memory (RAM) using Acurex Autograph data acquisition units which are periodically accessed from USA-CERL via telephone lines. A total of 372 data points are sampled on a minute-by-minute or continuous basis as appropriate, stored as hourly averages or totals respectively, and periodically transferred via telephone to IBM-AT microcomputers at USA-CERL where analysis occurs. Appendix A discusses the energy inputs and metering of each building group and the equipment used. Appendix B describes the software used to collect and review the data.

The quantity of hourly data that amasses over a year of collection at this level of effort is formidable but justified. In all building categories the multiple energy inputs (e.g., gas, electricity, circulated water) demanded multiple metering. Energy for heating, cooling, steam tables, and domestic hot water was often provided from a central plant, which made it necessary to monitor several parameters (e.g., flow rates and differential temperatures for each water loop) to quantify one component of energy use. In buildings of the size being investigated (sometimes consisting of three stories and nearly 40,000 sq ft of floor space), multiple interior temperature sensors were necessary to determine a representative indoor temperature.

In some cases, the statistical information recorded for hourly data (standard deviations, number of samples, etc.) allowed additional insight into the data on a minute as well as hourly basis. For instance, if both a total for an integrated channel and the count of readings that made up that total were stored, it was possible to generate and interpret for a component or system the total operation time, the percent operation time, and average minute readings. This additional information allowed a more informed interpretation of hourly values. Additionally, some redundant sensors were installed to ensure that needed information was obtained. The resultant data set is voluminous but necessary to estimate the impact of the retrofits in a side-by-side comparison.

Data Management

Software

Data analysis takes place on an IBM-AT using BASIC programs and Symphony* macros. Symphony is an integrated software package combining spreadsheet and data management facilities with graphics, editing, communication, and statistical capabilities. Macros are batch programs written in Symphony-defined code to execute sequential Symphony functions. BASIC Concerto, a Symphony add-on program, allows the programmer to mix BASIC and Symphony programming.

Data is stored in spreadsheet files. The spreadsheet is a grid of cells which can contain numbers, letters, or formulas. Each cell (a specific row and column location) can reference other cells and perform calculations on them. This capability allows interrelated data to be automatically updated as inputs change. For example, one row of information may contain temperature data which is used as an input for energy calculations in another row. Updating the temperature data row (perhaps changing the data from $^{\circ}$C to $^{\circ}$K) automatically updates the energy calculations of the energy row.

For this project, each cell of a spreadsheet contains a single data item. Each column contains data for a specific sensor; each row contains all data points for a given

*Symphony is a product of Lotus Development Corp.

hour. The Symphony spreadsheet allows calculations across columns (data items) and rows (hours) as long as each result is stored in a single cell and refers to specific column and row addresses. The spreadsheet environment does not easily allow conditional (if-then) selection of data from within the spreadsheet, nor does it easily allow conditional calculations across the entire data set.*

Due to the large number of parameters being logged for any one building in this project, the data base capabilities of Symphony were insufficient for the analysis. Therefore, specific programming in the spreadsheet environment was required for each type of analysis.

Conceptually, there is little difference between a spreadsheet and a data base environment in Symphony; however, the differences do become apparent with large scale data manipulations. When data stored in a spreadsheet can be sorted, extracted, printed, and summarized according to a given criteria, the spreadsheet is functioning like a data base. Symphony will automatically do these data base functions, but only for a spreadsheet which is 32 columns (data items) or less. Consequently, for spreadsheets which are larger, these database-like functions must be programmed manually using Symphony's macro programming language.

Data Organization

Once the data arrives at USA-CERL over the phone lines, it is collected into spreadsheet files each containing one week of data. Each file starts with data collected during the 2300 hour, Friday. In the case of missing data, a gap is left in the file, sot that data collected during the 2300 hour on Friday is always in the 168th row of data.

A weekly organization of the data was chosen because a week was a manageable unit of time that would provide similar response in energy totals and temperature trends from period to period, thus facilitating data troubleshooting. A daily time interval was not used because energy data for Saturday and Sunday would not compare directly with weekday data. Similarly, a given month would not compare to another month in the year because of unequal number of days and an unequal distribution of weekend days and weekdays. A quarterly (13-week) time unit might have been used, but besides losing resolution at this level, the data file size becomes unmanageable with the limitations of the available hardware and software.

To make the use of Symphony data files easier, Saturday (rather than a more standard Sunday or Monday) was chosen as the first day of the week. A Symphony function to identify the day of the week from date information was not available. However, Symphony does provide a modulo function (a truncated division), which can be used on the Symphony formatted date to identify a consistant day-of-week with Saturday as day 0 and Friday as day 6. Accepting Saturday as the start of the week was mathematically simple, and it had the added benefit of grouping the weekend responses when graphed versus time.

As stated earlier, missing data is represented by blank cells or gaps in the data files. The use of gaps in the record helps the Symphony analysis in several ways. Symphony spreadsheet commands are very row-specific in the handling of data and do not allow logical functions (e.g., "greater than"), unlike data base commands. For example, if a daily data summary were desired it would not be possible to search for data records

*The entire data set is made up of numerous weekly spreadsheet files.

desired would need to be identified. A sum of rows 1 to 24 for Saturday, rows 25 to 48 for Sunday, and so forth would be requested. This procedure is necessary because Symphony's data base functions do not allow selection over so large a data set.

Gaps in the data are also needed during graphing. Symphony, being row-specific, will graph the data item on the next row as the next point, regardless of whether it represents the next x value. Thus, when plotting a graph of data versus time for several buildings, if each row does not represent the same hour, the graph will be quite confusing for comparison.

File Management

The large number of weekly files must be categorized and stored in an easily retrievable format. When loading data files into application programs, it is important that naming follow a consistant and fairly simple convention. To this end, each building has been assigned a unique building letter (K through V), and each week was then identified by a year and week number. The file name was the combination of these codes. Additionally, logical disk drives identified K through V were created on hard disk so that a building code matched its disk identification letter. For example, the datafile for building K during week 25 of 1986 would be named "K:K8625". The reason for prioritizing the dates was that when the filenames are sorted (as they must be when manipulating over 800 files), all files for a building will be grouped together, and all data during a given year will also be grouped together and ordered by week.

Data Quality Assurance

A vigilant, painstaking effort has been made to establish a clean data set. The key obstacle in this effort was not the method of data collection, nor the type of data gathered, nor the equipment used but rather the volumes of data desired and the physical separation between the researchers and the test site. High quality instruments were purchased and installed; however, substantial human effort was necessary to oversee their operation. This section describes the manual and automated procedures used for detecting and cleaning up data anomalies.

A continuing challenge with the data cleanup is that only a certain amount of cleanup can be done automatically. That is, human judgment must evaluate conclusions drawn (errors flagged) by automated procedures. Any removal or repair of data must be done under manual control, because of the number of variables that must be considered. For instance, a Btu reading may not appear correct in and of itself, yet the analyst will consider the time of year, time of day, and values preceding and following the data point in question before taking corrective action. Potentially, algorithms could be developed to allow the software to interpret the data anomalies more thoroughly; however, current data cleanup procedures involve a substantial human effort.

Instrument Upkeep

Care for the data being gathered starts right at the source of the data: the sensors. Sensors and receivers are routinely inspected and calibrated to ensure data integrity. Details of the data acquisition and instrumentation hardware and its upkeep are given in Appendix A.

Daily Sampling of Data

Every day, each Acurex Autograph 800 data acquisition system is contacted by phone, and a single minute's worth of data is captured via a BASIC program and brought to the local IBM-AT. This data is compared to a set of acceptable high/low limits to test whether instruments are working properly. Additional records are kept regarding abnormal responses from the Autograph which might indicate hardware or modem problems. This analysis is performed to trap errors at the instrumentation and thus prevent the long term continuation of a single error.

Semiweekly Data Review

Hourly data is collected and analyzed twice a week. A program written in BASIC examines each data item against several criteria to diagnose errors which may escape the single minute analysis described above.

The semiweekly analysis is based on the concept that even a faulty instrument will provide an output of some kind. For instance, if a temperature sensor has been short circuited, it will show a consistent (but typically unreasonable) reading. This reading will be valid as far as the Autograph is concerned, and will be recorded as correct. This supposedly accurate temperature must be recognized as a short circuit, and corrective actions must be taken to prevent further loss of data. To this end, several common errors have been identified and are scanned for with the program:

1. Reversed leads on a sensor
2. Short circuit on a sensor
3. Open circuit on a sensor
4. Data above maximum range of instrument
5. Data below minimum range of instrument
6. Data above practical range of instrument
7. Data below practical range of instrument.

Of these tests, the first three would trap an error at the measuring device. Tests 4 and 5 typically indicate a problem in the hardware or possibly the programming of the Autograph. Tests 6 and 7 require special consideration because these errors typically indicate that an instrument may be drifting out of calibration or that the building operations are not as expected.

Practical limits can be defined as the range that the instrument readings will span under normal circumstances. For instance, an inside temperature in a heated space should not drop below 60 nor rise above 80 °F and hopefully should be maintained near 68 °F. Note, however, that temperatures outside of the 60 to 80 °F range are not necessarily incorrect and therefore must merely be treated as suspect. Each set of limits must be determined empirically or estimated theoretically for each measuring device.

It should be noted that the various error ranges overlap one another, which necessitates a prioritized logic for troubleshooting.

In many cases, such as gas use or water flow, a few zero readings may be correct but many zero readings in a row might indicate a fault. For instance, a barracks will use little (and perhaps none) of its domestic hot water between midnight and 0400 on weekdays. However it would be unusual if the same barracks used no hot water during any other 5-hour period of the day. Therefore, the length of time a particular reading remains the same is also examined.

Review of Weekly Files

Periodically (frequency depends on the backlog) the raw data is collected into weekly data files. When this is done, the data is visually surveyed for deviations in data patterns. Obvious errors such as an incorrect date, a row of zeros, or duplicate rows are found and corrected. These types of errors are typically generated when the data acquisition system is turned on or contacted by the data collection computer.

Another error trapping method uses summary sheets. Five types of summary sheets are made for this analysis. Each summary sheet compresses one week of data into one line, according to the type of summary performed. Currently summary sheets are created for data averages, minimums, maximums, actual totals, and projected totals. These sheets are compared to limits similar to those used in the scanning of raw minute data. When a fault is found in the data at this level of analysis, those particular hours are repaired where possible or removed from the weekly file.

Additionally, certain readings in the weekly files are compared to the manually observed meter readings. Manual readings are taken periodically on gas, electricity, gallons of condensate, and gallons of domestic hot water in selected buildings. This method has been used to trap gross errors in programming, calculations, conversion factors, etc.

The last method used to clean up the weekly files is a graphical survey of the data. This allows a visual examination of trends at each building. A 3 in. by 3 in. graph of parameters is prepared for each week for each building. Long term trends are examined by directly comparing the weekly response of one building with another. Additionally, comparing a building's response for one week with the same building's response for another week can pinpoint less obvious errors such as controls or instruments going out of calibration.

Direct Comparison Analysis

The direct energy comparison method described below requires energy use totals for a prescribed period of time (typically a year). The method of data sampling and gathering employed generates these totals by adding together numerous intermediate energy sums (made hourly) to arrive at an annual energy consumption. The percentage of hourly data gathered for this project has been very high, averaging 85 percent of all hours monitored. However to develop totals of annual consumption, it is necessary to use the gathered data to estimate the missing data.

Projections of energy totals are made on a weekly basis. From the masses of hourly data gathered, a mean hourly energy use is obtained for each building over a given week. From this a projection of weekly use is made by multiplying by the number of hours in the week (168). Several weekly values are then added together for a given period of time and the sums are compared. This direct comparison of energy used in each building category is made to determine savings.

The method of projecting totals on a weekly basis is used in an effort to minimize the impact of missing data on the final result. Missing data will (typically) be randomly distributed during a given week, and the weekly average should be reasonably close to the average of the missing data. In any case, the average of the missing data should probably be closer to the average of the week than to the average of the entire year, due to similar weather patterns within a week. In the cases where these assumptions do not hold, this process localizes errors to one week and hopefully makes them a small part of the comparison. When an entire week of data is missing, that week is replaced with the yearly average.

In some instances in this project, buildings have their own heat plants. This allows gas energy consumption to be measured both manually at the digital readout of the gas meter, and automatically with the datalogger summing up total pulses generated by the gas meter. But in many cases this is not an option, since heating or cooling is provided by a central plant, and individual building consumption is measured by metering the Btus delivered or removed by the circulated water.

In the cases where redundant consumption data are gathered, a comparison has been made between the manually gathered data and the data projected from datalogger readings. The results have compared favorably, with very good trend tracking. However, in some cases the projected totals have been somewhat lower than manual totals. The difference is assumed to be a result of the method of data extrapolation. It may not be optimal to use weekly averages to estimate the missing data. A more refined approach might be to estimate the blank consumption hours with data from the same week which was gathered in a similar hour with a similar load. These enhancements to data extrapolation as well as methods of comparison which are not so sensitive to the completeness of a data set will be investigated in the future.

5 INITIAL DATA ANALYSIS

This chapter presents an initial review of the data collected. It includes selections from the data, direct energy comparison analysis, preliminary estimates of energy savings, comparisons with BLAST estimates from USA-CERL TR E-183, and insights on operational trends. The reader should keep in mind while reviewing these analyses that the arduous task of data cleanup and analysis is not complete. Future data review may well refine current estimates.

Integrated Btu Calculations

Much of the data presented is for energy delivered or absorbed by circulating water for hot water heating or chilled water cooling. Energy delivered in the form of domestic hot water is also presented and based on energy changes in water. Energy (enthalpy) changes (Q) were determined by multiplying the total flow of circulating (or incoming) water (m, gal) by the temperature change in the water (T1 - T2, °F) by the specific heat of the water (Cp is about 8.2 Btu/°F x gal, depending on temperature conditions), or Q = m x Cp x (T1 - T2). Btus were computed in this fashion using a 1-minute integration period. Specific heats of water were assumed to be constant at nominal operating range values.

Energy Parameters Presented

For each building type, data are included for the test building, each reference building, and the average value of the reference buildings. Unless specified as manual meter readings, results are projected from the energy use recorded by the dataloggers. If hourly data was missing within a week, it was replaced by the average for that week. If data was missing for an entire week, that week's data was estimated by the average for the year.

Data points included in the analyses vary with the building category to reflect metered energy inputs for that group. Specific parameters reviewed for each building are detailed below.

Motor vehicle repair shop:

- Electricity
  - lighting, fans, compressors, tools, appliances, etc.

- Gas
  - boiler

L-shaped barracks:

- Electricity
  - lighting, fans, appliances, etc.

- Gas
  - boilers (space heating and domestic hot water), direct fired water heaters (domestic hot water)

- Heat delivered to individual heating zones
- Total heat delivered to building (sum zones 1, 2, 3)
- Energy in domestic hot water
- Heat removed in chilled water
  - central plant
- Heat total for the barracks wing (singled out to allow easier comparison with the energy predictions of the BLAST runs which did not include the mess hall wing [zone 3]).

Dining hall:

- Electricity
  - lighting, fans, appliances, etc.
- Gas
  - cooking
- Heat
  - circulating hot water from central plant
- Steam
  - kitchen use
- Energy in domestic hot water

Rolling pin barracks:

- Electricity
  - lighting, fans, appliances, etc.
- Heat
  - circulating hot water from central plant
- Energy in domestic hot water

Details of Tabular Information: Direct Energy Comparisons

Tables 7 through 14 present data on energy use observed in this project. These tables include energy used at the building site, as well as the source energy comparisons which refer to estimated energy use (in fossil fuel) at the source of power or heat production. Motor shops and L-shaped barracks have their own heat plant (boilers), so site and source energy use for gas are synonymous.

Each table is divided into four major sections. These sections, from left to right, represent: an energy summary, which presents totals for all energy types; a savings summary, which presents the savings observed or predicted for a given pair of buildings; a savings per square foot summary, which standardizes the magnitude of the savings observed; and an annual percent savings for a given pair of buildings. Note that the average data values of reference buildings of a given type are also included on these charts. Data listed as BLAST-normalized* has been adjusted for differences in weather conditions (heating degree days [HDDs] and cooling degree days [CDDs]) between the field test year and the BLAST-modeled year. Quantities listed under the BLAST model headings are results from the computer simulations summarized in TR E-183.

The energy summary shows annual energy totals in millions of Btus (MBtus). Energy totals are given as a foundation for further analysis which will compare building and source energy use on a percentage and square foot basis. The data from BLAST on the source energy table represent nonretrofit buildings.

The savings summary lists the computed annual energy savings (E_{svgs}) in MBtus for each test building. This is calculated by subtracting energy used by the test building (E_{tst}) from the energy used by the specified reference building or the mean of the reference buildings (E_{ref}), or $E_{svgs} = E_{ref} - E_{tst}$. The data from BLAST on the source energy table represent the expected savings if the suggested retrofits were made to the BLAST modeled building.

The energy savings per square foot summary presents annual energy savings divided by the amount of floor space, yielding units of thousands of Btus per square foot (kBtu/sqft). Note that the floor space used in the calculation is only the floor space over which that energy type is used. For this reason, the relevant floor space is also included in the chart.

The percent savings summaries are calculated from the energy savings divided by the individual (or mean) energy consumption of the reference buildings, $(E_{ref} - E_{tst})/E_{ref}$.

Source energy was determined by dividing the observed energy use by an assumed efficiency of the process that was used to generate that energy. For instance, it is assumed that when electricity is being generated, only 30 percent of the energy used in the process is actually delivered to the user. Similarly, heating is modeled with a source efficiency of 60 percent. Cooling is assumed to be produced with a chiller having a coefficient of performance (COP) of 3.0, thus being produced with an overall efficiency of 90 percent (which is calculated from COP times power production efficiency). These source efficiencies are the same efficiencies used by BLAST for its projections.

Preliminary Energy Results and Insights

Unless specified, energy comparisons with BLAST in this section are with source estimates made for Colorado Springs, which in many cases were higher than the all-site average savings referred to in Table 1 (Chapter 2). "All-site" data predicts energy consumption based on the average of data for the five geographic sites modeled by BLAST. Building consumption estimates are compared first on a component basis (system heating, building electricity, system cooling), and then on a total building system basis. Baseline energy consumptions for measured data are the average annual consumptions of

*Field energy totals were divided by observed degree days and then multiplied by degree days for the BLAST modeled year to allow comparison with BLAST results. Observed degree days were obtained from the National Oceanic and Atmospheric Administration (NOAA).

reference buildings. Discrepancies between expected and observed energy totals are noted, and potential interpretations are given. These interpretations will need futher consideration.

Motor Vehicle Repair Shops

Preliminary Results. Table 7 presents the site energy use at the motor vehicle repair shop. Table 8 reflects the source energy use for the same buildings. Figures 30 and 31 show sample trends in electric and gas use over time.

Measured baseline annual gas consumption (source heating energy) is 1801 MBtu when BLAST-normalized. BLAST-estimated annual baseline was 1799 MBtu. Direct comparison of measured gas consumption in the test building versus the average reference building usage shows a normalized annual gas savings of 573 MBtu, 119 kBtu/sq ft, or 31.8 percent of baseline consumption. BLAST had estimated a savings of 1029 MBtu, 214.4 kBtu/sq ft, or 57.2 percent of baseline gas consumption.

Annual source electrical estimates from BLAST had been 1004 MBtu for baseline consumption, with savings of 11 MBtu, 2.3 kBtu/sq ft, or 1.1 percent of baseline consumption for the motor shop. Source electrical consumption based on observed data is 171 MBtu, with savings of -44 MBtu, -9.1 kBtu/sq ft, or -25.6 percent of observed baseline. Note that negative savings indicates increased consumption of test building over reference buildings.

Total annual building energy consumption at Colorado Springs had been estimated by BLAST at 2803 MBtu, with total anticipated savings of 1040 MBtu, 216.7 kBtu/sq ft, or 37 percent of annual baseline. All-site average BLAST projections had been for annual consumption of 2002 MBtu, with savings of 696 MBtu, 145 kBtu/sq ft, or 35 percent of annual baseline. Observed building totals show normalized annual energy consumption at 1972 MBtu, with net savings of 529 MBtu, 110 kBtu/sq ft, or 26.8 percent of baseline consumption.

Insights. Observed reductions in heating consumption at the motor pool totaled 31.8 percent, while increased electrical consumption of 25.6 percent over reference buildings brought the net building savings to 26.8 percent. This overall savings of 26.8 percent was a substantial reduction in baseline consumption, but well below anticipated savings. Actual net Btus saved were 51 percent of that projected by BLAST. Many factors may be contributing to the differences in anticipated versus observed energy savings.

While baseline heating consumption estimates were right on target with those observed, electrical estimates were of a different order of magnitude than actual usage. Although the anticipated energy savings in electricity was a small portion of the overall savings, investigating the reasons for the discrepancy may reveal the applied (as opposed to theoretical) effectiveness of the retrofit package. That is, the electricity patterns may indicate that the buildings were not used as initially modeled and therefore indicate that heating totals need adjustment. Or it may be that the energy saved in heating is diminished by an increased need for lighting now that a large portion of the windows are covered.

The difference in projected versus observed baseline electrical consumption may be due to a lower building occupation than initially predicted, or to differences in use of electrically powered machinery in the vehicle repair stations, or to an inappropriate use of calibration data for the BLAST models.

Table 7

Site Energy Use: Motor Vehicle Repair Shop Test/Reference Direct Comparison (Preliminary) July 1986-June 1987

Annual Site Energy Summary

	Building 633 (MBtu)	Building 634 (MBtu)	Building 635 (MBtu)	Building 636 (MBtu)	Mean Reference (MBtu)
Elec ‡	64	83	15	56	51
Gas ‡	1061	1498	1328	1838	1555
Elec & Gas	1125	1582	1343	1894	1608

Annual Energy Savings Summary

	633 vs 634 (MBtu)	633 vs 635 (MBtu)	633 vs 636 (MBtu)	633 vs Mean Reference (MBtu)
Elec ‡	19	-50	-9	-13
Gas ‡	438	268	778	494
Elec & Gas	457	218	789	481

Annual Savings Per Sq. Ft.

	(Sq.Ft.)	633 vs 634 (KBtu/sq.ft.)	633 vs 635 (KBtu/sq.ft.)	633 vs 636 (KBtu/sq.ft.)	633 vs Mean Ref. (KBtu/sq.ft.)
Elec ‡	4800	4.0	-10.4	-1.8	-2.7
Gas ‡	4800	91.2	55.8	162.1	103.0
Elec & Gas	4800	95.1	45.4	160.3	100.3

Annual Percent Savings Summary

	633 vs 634 (%)	633 vs 635 (%)	633 vs 636 (%)	633 vs Mean Reference (%)
Elec ‡	22.8%	-340.4%	-15.4%	-25.6%
Gas ‡	29.2%	20.2%	42.3%	31.8%
Elec & Gas	28.9%	16.2%	40.6%	30.0%

‡ From meter readings.

Key

1 MBtu = 10^6 Btu
1 KBtu = 10^3 Btu
1 Kwh = 3413 Btu
1 Cubic Foot Gas = 1030 Btu
1 MBtu = 1.055 GJ

Building 633 = Test
Building 634 = Reference
Building 635 = Reference
Building 636 = Reference

NA = Data Not Available

Table 8

Source Energy Use: Motor Vehicle Repair Shop Test/Reference Direct Comparison (Preliminary) July 1986-June 1987

Annual Source Energy Summary

	Source Effic. (%)	Building 633 (MBtu)	Building 634 (MBtu)	Building 635 (MBtu)	Building 636 (MBtu)	Mean Reference (MBtu)	Blast Model (MBtu)
Elec	30%	214	278	49	186	171	1004
Gas	100%	1061	1498	1328	1838	1555	
Blast Normalized		1228	1735	1538	2129	1801	1799
Elec & Gas		1275	1776	1377	2024	1726	
Blast Normalized		1443	2013	1587	2315	1972	2803

Annual Source Energy Savings

	633 vs 634 (MBtu)	633 vs 635 (MBtu)	633 vs 636 (MBtu)	633 vs Mean Reference (MBtu)	Savings from Blast Model (MBtu)
Elec	63	-166	-29	-44	11
Gas	438	268	778	494	
Blast Normalized	507	310	901	573	1029
Elec & Gas	501	102	749	451	
Blast Normalized	570	144	872	529	1040

Annual Source Energy Savings Per Sq. Ft.

	Floor Space (Sq.Ft.)	633 vs 634 (KBtu/sq.ft.)	633 vs 635 (KBtu/sq.ft.)	633 vs 636 (KBtu/sq.ft.)	633 vs Mean Ref. (KBtu/sq.ft.)	Savings, Blast Model (KBtu/sq.ft.)
Elec	4800	13.2	-34.5	-6.0	-9.1	2.3
Gas	4800	91.2	55.8	162.1	103.0	
Blast Normalized	4800	105.6	64.6	187.7	119.3	214.4
Elec & Gas	4800	104.4	21.3	156.1	93.9	
Blast Normalized	4800	118.8	30.1	181.7	110.2	216.7

Annual Percent Savings at Energy Source

	633 vs 634 (%)	633 vs 635 (%)	633 vs 636 (%)	633 vs Mean Reference (%)	Savings from Blast Model (%)
Elec	22.8%	-340.4%	-15.4%	-25.6%	1.1%
Gas	29.2%	20.2%	42.3%	31.8%	
Blast Normalized	29.2%	20.2%	42.3%	31.8%	57.2%
Elec & Gas	28.2%	7.4%	37.0%	26.1%	
Blast Normalized	28.3%	9.1%	37.7%	26.8%	37.1%

NOAA HDD (Fort Carson Jul 1986-April 1987; Colorado Springs May 1987-June 1987, due to availability): 5539   Blast HDD: 6415

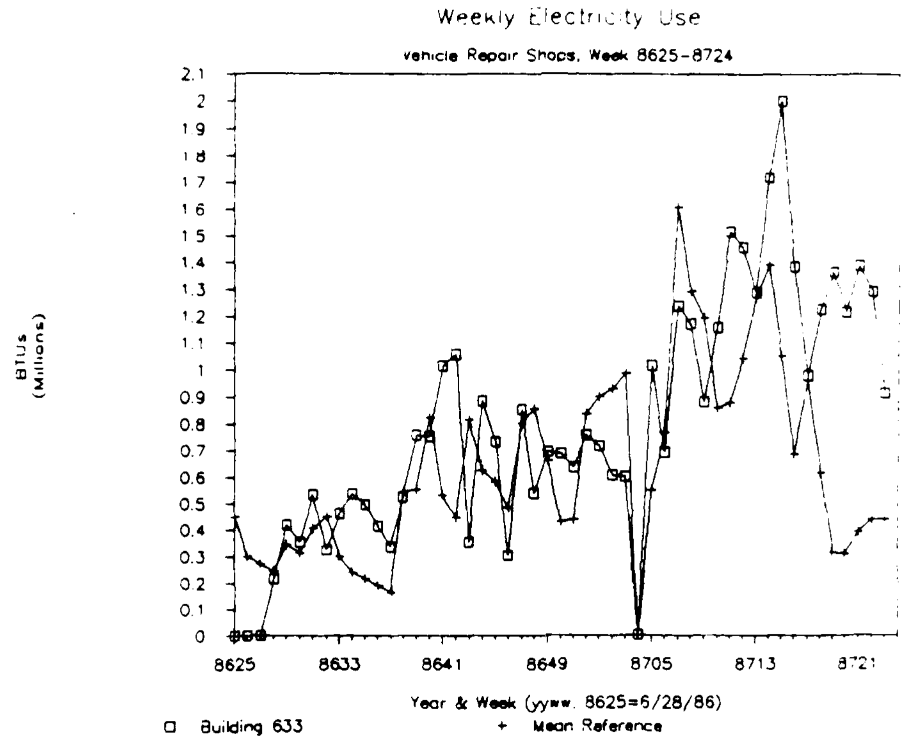

Figure 30. Weekly electricity use of motor vehicle repair shops, week 8625 – week 8724

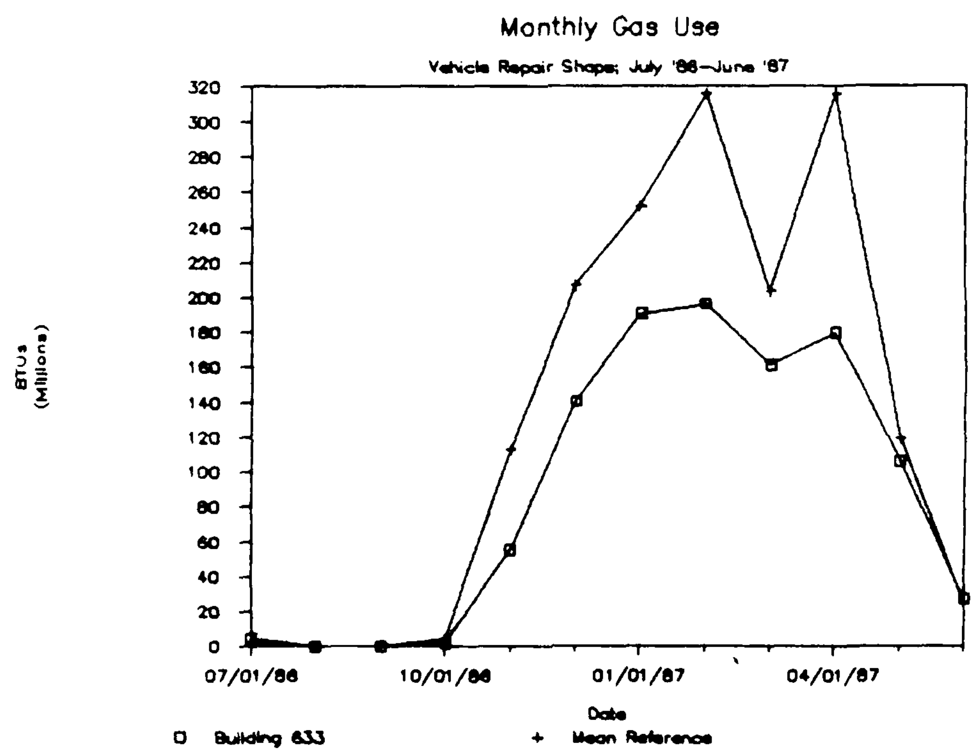

Figure 31. Monthly gas use of motor vehicle repair shops.

Of further concern is the variability in electrical consumption between buildings. Identifying a 26 percent increase in electrical consumption by direct comparison may not be appropriate given that electric use at building 635 is significantly different from consumption in the other two reference buildings. Statistical review of the information in the future may suggest that the consumption of 635 should not be considered in the average reference baseline.

Lower than expected savings in heating may be due in large part to the disabling of thermostatically-controlled night setback temperatures. An investigation into the causes of the adjustment, followed by an appropriate remedy, may bring about the desired energy savings.

Additionally, lower than anticipated savings in heating may be due to the observed compromising of the building envelope, in particular, open overhead doors and broken windows in the vehicle stations. It has been observed that overhead doors are often raised during the heating season to allow unrestricted entrance and exit to the building and to allow for the venting of vehicle exhaust from the building. To better realize the energy savings potential of the retrofits it may necessary to provide easy access to the building which does not require the present task of raising and lowering an overhead door. Motorized door openers, air curtains, or swinging entrance doors may all be reasonable options. Furthermore, it may be appropriate to disable heater operation when overhead doors are open. This may provide the appropriate incentive for occupants to make use of exhaust sleeves which allow venting of vehicle exhaust without opening doors. Numerous windows were broken after the retrofit, challenging the effectiveness of retrofit measures. Prompt repair and breakage prevention will help the energy efficiency of the building.

L-Shaped Barracks

Preliminary Results. Table 9 presents the site energy use at the L-shaped barracks. Table 10 reflects the source energy for the same buildings. Figures 32, 33, and 34 show the trends in electric, gas, and heating use over time.

Measured baseline annual gas consumption (source heating energy) for the L-shaped barracks is 7502 MBtu. Savings for source gas is 1724 MBtu, 45.4 kBtu/sq ft, or 23 percent of observed baseline. Gas consumption for these buildings includes energy for heating and domestic hot water.

BLAST did not model the whole building, but only the barracks wing (zones 1 and 2) in its energy estimates. For comparison with BLAST estimates, datalogger totals of heating Btus delivered to zones 1 and 2 were divided by the BLAST estimated source efficiency of 60 percent and normalized by heating degree days. Based on normalized datalogger totals, the estimated baseline annual source heating energy for the barracks wing is 3361 MBtu. The BLAST estimate for the barracks wing annual baseline was 4133 MBtu. Direct comparison of barracks wing heating energy consumption in the test building versus average reference building use shows a normalized annual heating energy savings of 1452 MBtu, 46.7 kBtu/sq ft, or 43 percent of baseline consumption. BLAST had estimated a savings of 2424 MBtu, 77.9 kBtu/sq ft, or 59 percent of baseline fuel consumption.

Annual source electrical estimates from BLAST had been 2260 MBtu for baseline consumption, with savings of 196 MBtu, 6.3 kBtu/sq ft, or 8.67 percent of baseline consumption for the barracks wing. Source electrical consumption based on observed data for the entire building (not just barracks wing) is 2613 MBtu, with savings of 392 MBtu, 10.3 kBtu/sq ft, or 15 percent of observed baseline.

Table 9

Site Energy Use: L-Shaped Barracks Test/Reference Direct Comparison (Preliminary) January 1986-December 1986

	Annual Site Energy Summary				Annual Energy Savings			Annual Energy Savings Per Sq. Ft.				Annual Percent Savings		
	Bdlg 811 (MBtu)	Bdlg 812 (MBtu)	Bdlg 813 (MBtu)	Mean Ref. (MBtu)	811 vs 812 (MBtu)	811 vs 813 (MBtu)	811 vs Mean Ref. (MBtu)	Floor Space (sq.ft.)	811 vs 812 (KBtu/sq.ft)	811 vs 813 (KBtu/sq.ft)	811 vs Mean Ref. (KBtu/sq.ft)	811 vs 812 (%)	811 vs 813 (%)	811 vs Mean Ref. (%)
Elec	666	818	750	784	152	84	118	38000	4.0	2.2	3.1	18.5%	11.1%	15.0%
Gas	5778	7463	7542	7502	1685	1764	1724	38000	44.3	46.4	45.4	22.6%	23.4%	23.0%
Zone 3	108	257	157	207	149	50	99	6878	21.7	7.2	14.5	58.1%	31.6%	48.0%
Zone 2	434	956	494	725	522	60	291	15561	33.6	3.9	18.7	54.6%	12.2%	40.2%
Zone 1	463	777	931	854	314	468	391	15561	20.2	30.1	25.1	40.4%	50.3%	45.8%
Heating Total	1004	1990	1582	1786	985	578	782	38000	25.9	15.2	20.6	49.5%	36.5%	43.8%
Zone 1&2 Total	897	1733	1425	1579	836	528	682	31122	26.9	17.0	21.9	48.3%	37.1%	43.2%
DHW	744	769	595	682	26	-149	-61	38000	0.7	-3.9	-1.6	3.4%	-25.0%	-9.0%
Cooling	187	260	119	190	73	-68	3	38000	1.9	-1.8	0.1	28.1%	-57.1%	1.3%
Gas, Elec, Cool	6632	8541	8411	8476	1909	1779	1844	38000	50.2	46.8	48.5	22.4%	21.2%	21.8%

Key

1 MBtu = 10^6 Btu
1 KBtu = 10^3 Btu
1 Kwh = 3413 Btu
1 Cubic Foot Gas = 1030 Btu
1 MBtu = 1.055 GJ

Building 811 = Test
Building 812 = Reference
Building 813 = Reference

NA = Data Not Available

Table 10

Source Energy Use: L-Shaped Barracks Test/Reference Direct Comparison (Preliminary)
January 1986-December 1986

	Annual Source Energy Summary						Annual Source Energy Savings				Annual Source Energy Savings Per Sq. Ft.						Annual Prt. Savings at Energy Source			
	Source Effic. (%)	Bdlg 811 (MBtu)	Bdlg 812 (MBtu)	Bdlg 813 (MBtu)	Mean Ref. (MBtu)	Blast Ref. Model (MBtu)	811 vs 812 (MBtu)	811 vs 813 (MBtu)	811 vs Mean Ref. (MBtu)	Savings from Blast Model (MBtu)	Floor Space (sq.ft.)	811 vs 812 (KBtu/ sq.ft)	811 vs 813 (KBtu/ sq.ft)	811 vs Mean Ref. (KBtu/ sq.ft)	Blast Model Floor Space (sq.ft.)	Savings, Blast Model (KBtu/ sq.ft)	811 vs 812 (%)	811 vs 813 (%)	811 vs Mean Ref. (%)	Savings from Blast Model (%)
Elec	30%	2221	2726	2500	2613	2260	505	278	392	196	38000	13.3	7.3	10.3	31122	6.3	18.5%	11.1%	15.0%	8.7%
Gas	100%	5778	7463	7542	7502		1685	1764	1724		38000	44.3	46.4	45.4			22.6%	23.4%	23.0%	
Zone 3	60%	179	428	262	345		249	83	166		6878	36.2	12.0	24.1			58.1%	31.6%	48.0%	
Zone 2	60%	723	1594	824	1209		870	100	485		15561	55.9	6.4	31.2			54.6%	12.2%	40.2%	
Zone 1	60%	771	1295	1551	1423		523	780	652		15561	33.6	50.1	41.9			40.4%	50.3%	45.8%	
Heating Total	60%	1674	3317	2637	2977		1643	963	1303		38000	43.2	25.3	34.3			49.5%	36.5%	43.8%	
Zone 1&2 Total	60%	1495	2889	2375	2632		1394	880	1137		31122	44.8	28.3	36.5			48.3%	37.1%	43.2%	
Blast Normalized		1909	3689	3033	3361	4133	1780	1124	1452	2424	31122	57.2	36.1	46.7	31122	77.9	48.3%	37.1%	43.2%	58.6%
Cooling	90%	208	289	132	211		81	-76	3		38000	2.1	-2.0	0.1			28.1%	-57.1%	1.3%	
Blast Normalized		265	369	169	269	922	104	-97	4	719	38000	2.7	-2.5	0.1	31122	23.1	28.1%	-57.1%	1.3%	78.0%
Gas, Elec, Cooling		8265	10558	10210	10384		2293	1945	2119			59.8	51.7	55.7			21.7%	19.1%	20.4%	
Elec & Zone 1&2		3716	5615	4874	5245		1899	1158	1529			58.1	35.6	46.8			33.8%	23.8%	29.1%	
Blast Normalized		4746	7172	6226	6699	6393	2425	1479	1952	2620		74	45	60		101.0	33.8%	23.8%	29.1%	41.0%
Elec, Zone 1&2, Cool		3924	5904	5007	5455		1980	1083	1531			60.21	33.61	46.91			33.5%	21.6%	28.1%	
Blast Normalized		5012	7541	6395	6968	7315	2529	1383	1956	3339		77	43	60	31122	107.3	33.5%	21.6%	28.1%	45.6%

NOAA HDD (Ft. Carson data Jan 1986-Dec 1986): 5023 Blast HDD: 6415
NOAA CDD (Ft. Carson data Jan 1986-Dec 1986): 522 Blast CDD: 531 (CDD for 1986 was estimated by NOAA)

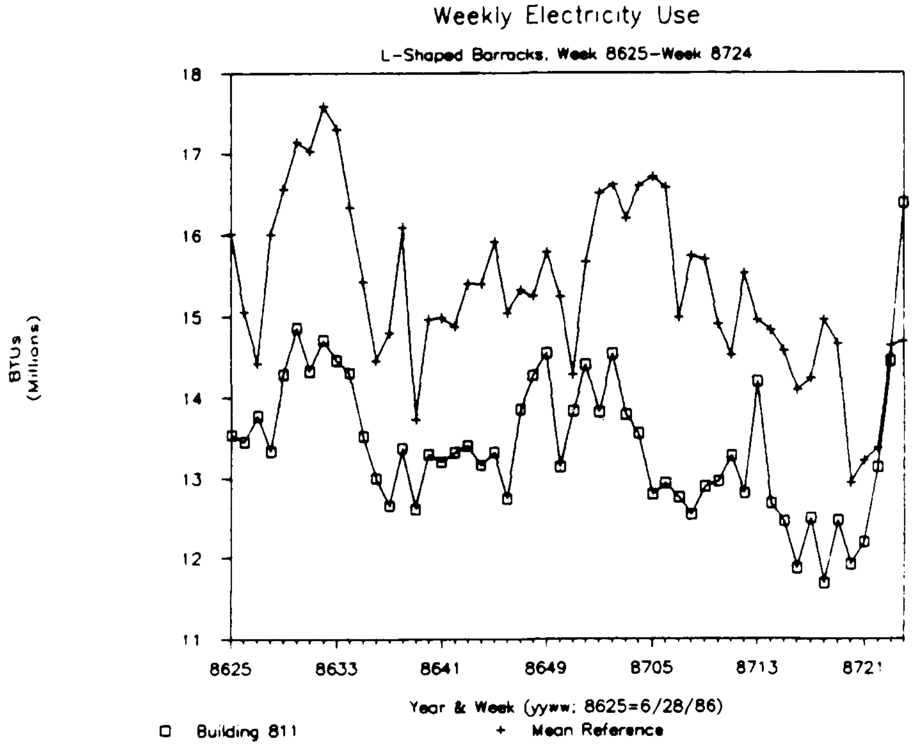

Figure 32. Weekly electricity use of L-shaped barracks, week 8625 - week 8724.

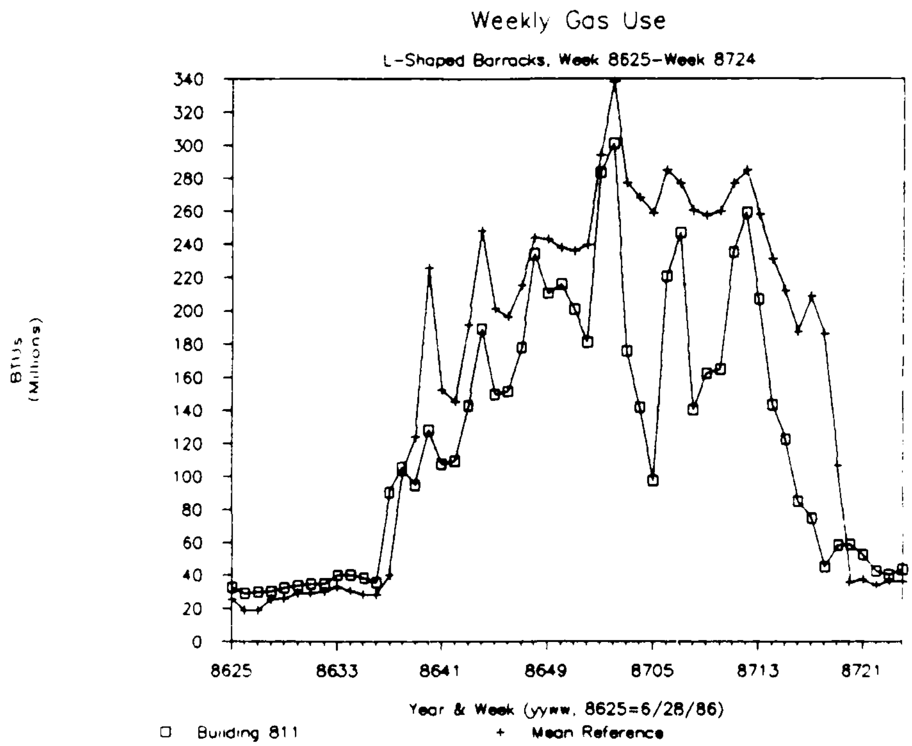

Figure 33. Weekly gas use of L-shaped barracks, week 8625 - week 8724.

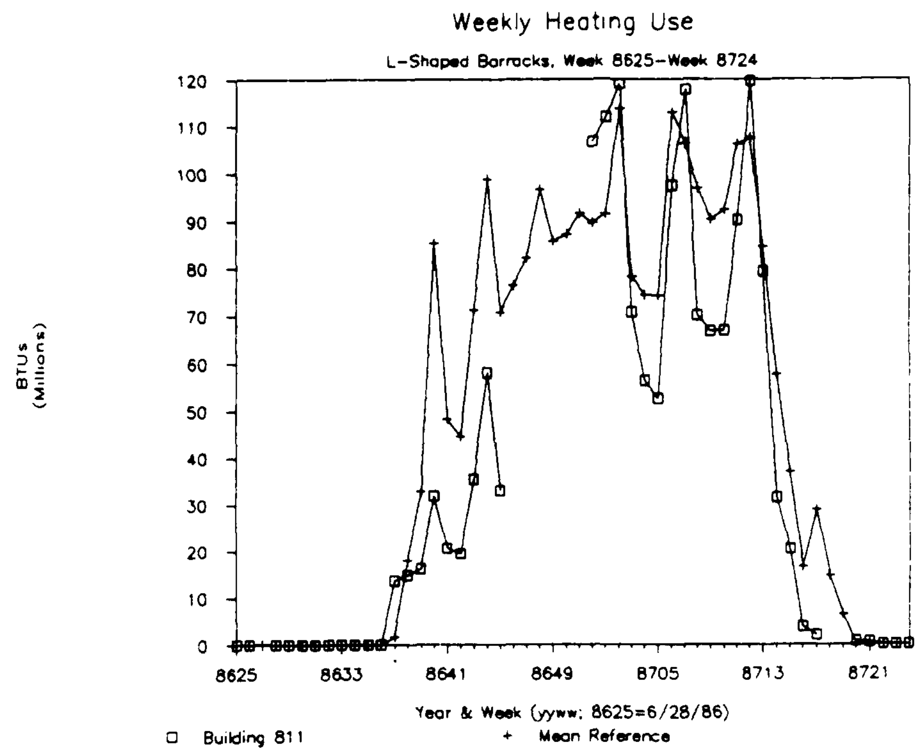

Figure 34. Weekly heating use of L-shaped barracks, week 8625 - week 8724.

Annual source cooling energy estimates from BLAST were 922 MBtu for baseline consumption, with savings of 719 MBtu, 23.1 kBtu/sq ft, or 78 percent of baseline consumption for the barracks wing. Source cooling energy requirement based on normalized observed data for the entire building (not just barracks wing) is 269 MBtu, with savings of 4 MBtu, 0.1 kBtu/sq ft, or 1.3 percent of observed baseline.

Total annual L-shaped barracks energy consumption at Colorado Springs had been estimated by BLAST at 7315 MBtu, with a total anticipated savings of 3339 MBtu, 107.3 kBtu/sq ft, or 46 percent of annual baseline. All-site average BLAST projections had been for an annual consumption of 6904 MBtu, with savings of 2932 MBtu, 91 kBtu/sq ft, or 41 percent of annual baseline. Observed building totals show annual energy consumption (prorated for heating only),* at 6968 MBtu, with net savings of 1956 MBtu, 60 kBtu/-sq ft, or 28 percent of baseline consumption.

Insights. Observed reductions in heating consumption at the L-Shaped Barracks totaled 43 percent. That, coupled with savings in electrical consumption of 15 percent and a savings in cooling consumption of 1.3 percent brought the net building savings to 28 percent. This overall savings of 28 percent was a substantial reduction in baseline consumption, but below anticipated savings. Actual net Btus saved were 59 percent of that projected by BLAST. Many factors may be contributing to the differences in anticipated versus observed energy savings.

*Heating component of building energy total is for barracks wing only. Electric and cooling components are for the entire building due to lack of submetering.

Calculations of baseline energy consumption by BLAST for heating and electricity were in good agreement with those measured. Additionally, measured data had good consistency between buildings. Savings of Btus in heating and electricity were 60 percent and 200 percent of anticipated.

BLAST calculations of cooling baseline consumption however, were much higher than those observed. The differences in cooling energy consumption may be due to the fact that the existing cooling systems cannot meet the demands on them. Although chilled water is pumped continuously from the central plant without restriction at the buildings, the temperature of the water supplied is not cold enough to cool down the conditioned space. The result is that the buildings are consistently warm in the summer and windows are opened to circulate building air. Comparisons in cooling consumptions given these conditions are ambiguous. Additionally, cooling system modeling with BLAST may have been inappropriate. L-shaped observed cooling data matches better with BLAST estimated load for the rolling-pin barracks than with estimated load for the L-shaped barracks.

The lower than anticipated savings in heating may be due to the observed compromising of the building envelope, in particular, open windows. Current data indicate that interior spaces are consistently overheated in winter, prompting inhabitants to open windows to maintain interior comfort. This compromising of the building envelope during heating seasons results in excessive energy loss. The hot water heating systems in the barracks buildings are regulated by outside air temperatures without feedback from the conditioned space. Enhanced control and heat distribution which responds to the actual demand for heat in the conditioned space should increase the comfort and economical energy use.

An additional consideration the data raises is the low heating system efficiencies. The data show annual system efficiencies of 29 to 37 percent as opposed to the BLAST-assumed efficiency for heating of 60 percent. An overhaul of the heat production systems appears opportune. Substantial savings could be realized through careful evaluation of the sources of the inefficiencies, followed by tune-up, repair, and (if necessary) replacement or enhancement of insufficiently functioning equipment.

Dining Halls

Preliminary Results. Table 11 presents the site energy use at the dining halls. Table 12 reflects the source energy data for the same buildings. Figures 35 and 36 show sample trends in electric and heating use over time.

Based on datalogger totals (BLAST-normalized), the estimated baseline annual heating source consumption is 812 MBtu. BLAST-estimated annual baseline was 4498 MBtu. Direct comparison on source heating consumption (heating btus delivered divided by assumed source efficiency) in the test building versus average reference building usage shows a normalized annual heating energy savings of 190 MBtu, 18 kBtu/sq ft, or 23 percent of baseline consumption. BLAST had estimated a savings of 3134 MBtu, 295.1 kBtu/sq ft or 69.7 percent of baseline heating consumption.

Annual source electrical estimates from BLAST had been 2255 MBtu for baseline consumption, with savings of 486 MBtu, 45.8 kBtu/sq ft, or 21.6 percent of baseline consumption for the dining halls. The estimate of annual source electrical consumption based on observed data is 111 MBtu, with savings of 16 MBtu, 1.5 kBtu/sq ft, or 14.5 percent of observed baseline.

Table 11

Site Energy Use: Dining Hall Test/Reference Direct Comparison (Preliminary) July 1986-June 1987

	Annual Site Energy Summary				Annual Energy Savings			Annual Energy Savings Per Sq. Ft.				Annual Percent Savings		
	Building 1361 (MBtu)	Building 1369 (MBtu)	Building 1669 (MBtu)	Mean Reference (MBtu)	1361 vs 1369 (MBtu)	1361 vs 1669 (MBtu)	1361 vs Mean Reference (MBtu)	Floor Space (sq.ft.)	1361 vs 1369 (KBtu/ sq.ft.)	1361 vs 1669 (KBtu/ sq.ft.)	1361 vs Mean Ref. (KBtu/ sq.ft.)	1361 vs 1369 (%)	1361 vs 1669 (%)	1361 vs Mean Reference (%)
Elec #	28	51	16	33	22	-13	5	10620	2.1	-1.2	0.5	44.1%	-82.1%	14.5%
Cooking Gas	2893	127	751	439	-2766	-2142	-2454	10620	-260.4	-201.7	-231.1	-2176.0%	-285.3%	-559.1%
Heat ##	318	604	225	414	286	-93	97	10620	26.9	-8.7	9.1	47.4%	-41.3%	23.3%
Steam	4067	742	2315	1528	-3325	-1752	-2539	10620	-313.1	-165.0	-239.0	-448.1%	-75.7%	-166.1%
DHW	1376	263	NA	NA	-1113	NA	NA	10620	-104.8	NA	NA	-422.6%	NA	NA
Elec & Heat	346	655	240	448	309	-106	101	10620	29.1	-9.9	9.6	47.1%	-43.9%	22.7%

From meter readings. ## Annualized from part year data, based upon heating degree days.

Key

1 MBtu = 10^6 Btu
1 KBtu = 10^3 Btu
1 Kwh = 3413 Btu
1 Cubic Foot Gas = 1030 Btu
1 MBtu = 1.055 GJ

Building 1361 = Test
Building 1369 = Reference
Building 1669 = Reference

NA = Data Not Available

Table 12

Source Energy Use: Dining Hall Test/Reference Direct Comparison (Preliminary) July 1986-June 1987

	Annual Source Energy Summary						Annual Source Energy Savings				Annual Source Energy Savings Per Sq. Ft.					Annual Pct. Savings at Energy Source			
	Source Effic. (%)	Building 1361 (MBtu)	Building 1369 (MBtu)	Building 1669 (MBtu)	Mean Reference (MBtu)	Blast Model (MBtu)	1361 vs 1369 (MBtu)	1361 vs 1669 (MBtu)	1361 vs Mean Reference (MBtu)	Savings from Blast Model (MBtu)	(sq.ft.)	1361 vs 1369 (KBtu/ sq.ft.)	1361 vs 1669 (KBtu/ sq.ft.)	1361 vs Mean Ref. (KBtu/ sq.ft.)	Savings, Blast Model (KBtu/ sq.ft.)	1361 vs 1369 (%)	1361 vs '+69 (%)	1361 vs Mean Reference (%)	Savings from Blast Model (%)
Elec	30%	95	169	52	111	2255	75	-43	16	486	10620	7.0	-4.0	1.5	45.8	44.1%	-82.1%	14.5%	21.6%
Heat	60%	529	1006	375	691		477	-155	161		10620	44.9	-14.6	15.2		47.4%	-41.3%	23.3%	
Blast Normalized		623	1183	441	812	4498	561	-182	190	3134	10620	53	-17	18	295.1	47.4%	-41.3%	23.3%	69.7%
Elec & Heat		624	1176	427	801		552	-197	177		10620	51.9	-18.6	16.7		46.9%	-46.2%	22.1%	
Blast Normalized		734	1383	502	942	6753	649	-232	208	3620		61	-22	20	340.8	46.9%	-46.2%	22.1%	53.6%

NOAA HDD (Fort Carson Jul 1986-April 1987; Colorado Springs May 1967-June 1987, due to availablity): 5539 Blast HDD: 6514

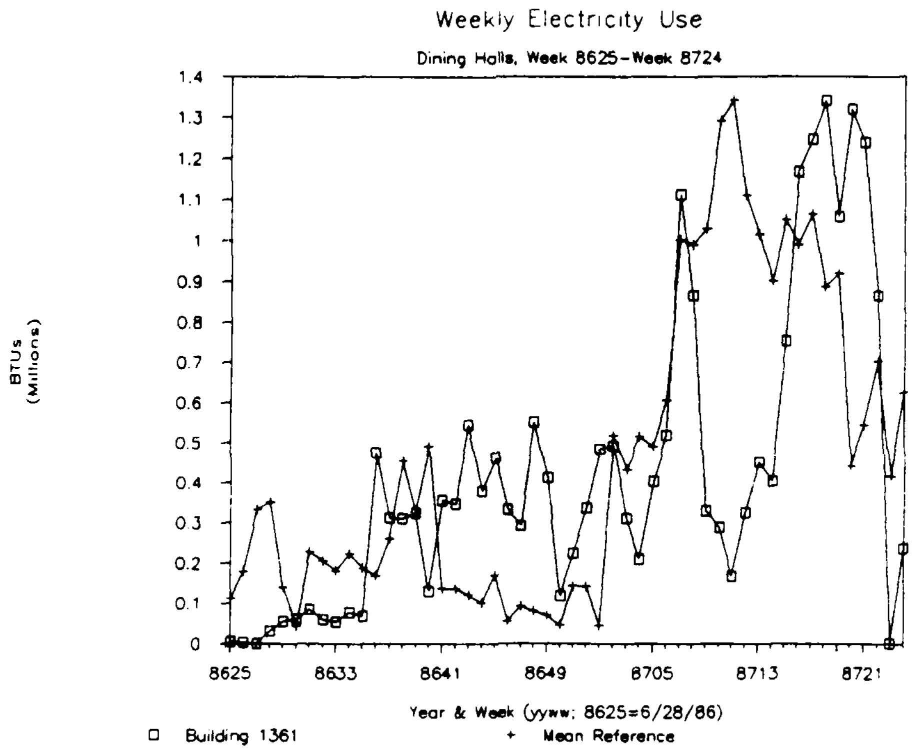

Figure 35. Weekly electricity use of dining hall week 8625 - week 8724.

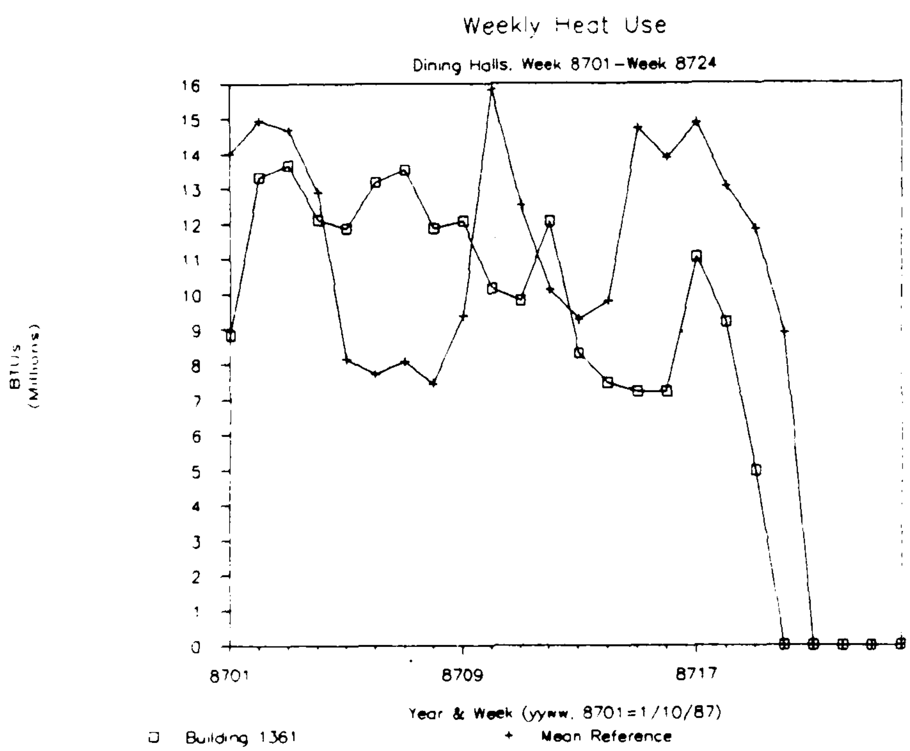

Figure 36. Weekly heating use of dining hall, week 8701 - week 8724.

The BLAST models had included cooling air in the dining halls which was not the case at Colorado Springs. Unless specified, total building energy consumptions discussed below are given on the basis of heating and electricity only.

Total annual building energy consumption at Colorado Springs had been estimated by BLAST at 6753 MBtu, with a total anticipated savings of 3620 MBtu, 341 kBtu/sq ft, or 54 percent of annual baseline. All-site average BLAST projections had been for annual consumption (cooling included) of 5225 MBtu, with savings of 2092 MBtu, 197 kBtu/sq ft, or 40 percent of annual baseline. Observed building totals show normalized annual energy consumption at 942 MBtu, with net savings of 208 MBtu, 20 kBtu/sq ft, or 22.1 percent of baseline consumption.

Insights. Observed reductions in heating consumption at the enlisted personnel dining facility totaled 23 percent. That, coupled with savings in electrical consumption of 14.5 percent brought the net building savings to 22 percent. This overall savings of 22 percent was a good reduction in baseline consumption, but in actual Btus it was substantially below anticipated savings. Actual net Btus saved were 6 percent of that projected by BLAST. Various factors may be contributing to the differences in anticipated versus observed energy savings.

Calculations of baseline energy consumption by BLAST were higher than those measured, so even if the percent reduction had matched BLAST assessments, actual Btus saved would have been lower. Both heating and electric consumption estimates were of a different order of magnitude than actual usage. There was also wide variability in energy use between buildings. Understanding these discrepancies may require examining the use of these buildings. Information gathered on numbers of meals served in these facilities indicates that the buildings were frequently closed. Alternately, data used for calibrating this BLAST model may not have been representative since data for this category encompassed a variety of public building types. These possibilities for discrepancies will need to be reviewed in the future.

Use of cooking gas and kitchen steam in the test building indicates significantly more building use than in the reference buildings. This building use would also imply that the doors were opened more than in the reference buildings, causing infiltration which was not affecting the reference buildings. It may be appropriate to factor this usage information into savings calculations in the future.

A further reason for the differences between anticipated and observed totals may well be due to the fact that the actual building system does not have air cooling which was assumed in the BLAST models.

Rolling Pin Barracks

Preliminary Results. Table 13 presents the site energy use at the rolling pin barracks. Table 14 reflects the source energy data for the same buildings. Figures 37 and 38 show sample trends in electric and heating use over time.

The estimated source consumption baseline for annual heating energy based on normalized datalogger readings is 6171 MBtu. The BLAST-estimated annual baseline was 5572 MBtu. Direct comparison of source heating consumption (heating Btus delivered divided by assumed source efficiency) in the test building versus average reference building usage shows a normalized annual heating energy savings of 2338 MBtu, 57.4 kBtu/sq ft, or 38 percent of baseline consumption. BLAST had estimated a savings of 3334 MBtu, 81.9 kBtu/sq ft or 60 percent of baseline heating consumption.

Table 13

Site Energy Use: Rolling Pin Barracks Test/Reference Direct Comparison (Preliminary)
July 1986-June 1987

	Annual Site Energy Summary					Annual Energy Savings Summary				Annual Savings Per sq. ft.					Annual Percent Savings Summary			
	Building 1363 (MBtu)	Building 1663 (MBtu)	Building 1666 (MBtu)	Building 1667 (MBtu)	Mean Reference (MBtu)	1363 vs 1663 (MBtu)	1363 vs 1666 (MBtu)	1363 vs 1667 (MBtu)	1363 vs Mean Reference (MBtu)	Floor Space (sq. ft.)	1363 vs 1663 (kBtu/ sq.ft.)	1363 vs 1666 (kBtu/ sq.ft.)	1363 vs 1667 (kBtu/ sq.ft.)	1363 vs Mean Ref. (kBtu/ sq.ft.)	1363 vs 1663 (%)	1363 vs 1666 (%)	1363 vs 1667 (%)	1363 vs Mean Reference (%)
Elec *	700	187	42	627	285	-513	-659	-73	-415	40698	-12.6	-16.2	-1.8	-10.2	-274.7%	-1586.7%	-11.7%	-145.6%
Heat	1986	2849	4264	2479	3197	863	2278	493	1211	40698	21.2	56.0	12.1	29.8	30.3%	53.4%	19.9%	37.9%
DHW	145	366	599	313	426	221	454	168	281	40698	5.4	11.1	4.1	6.9	60.3%	75.7%	53.6%	65.9%
Cool	264	NA	NA	NA	NA	NA	NA	NA	NA	40698	NA	NA	NA	NA	NA	NA	NA	NA
Elec & Heat	2686	3035	4305	3105	3482	349	1619	419	796	40698	8.6	39.8	10.3	19.6	11.5%	37.6%	13.5%	22.9%
Elec, Heat, & Cooling	2950	NA	NA	NA	NA	NA	NA	NA	NA	40698	NA	NA	NA	NA	NA	NA	NA	NA

* From meter readings.

Key

1 MBtu = 10^6 Btu
1 kBtu = 10^3 Btu
1 kwh = 3413 Btu
1 Cubic Foot Gas = 1030 Btu
1 MBtu = 1.055 GJ

Building 1363 = Test
Building 1369 = Reference
Building 1666 = Reference
Building 1667 = Reference

NA = Data Not Available

Table 14

Source Energy Use: Rolling Pin Barracks Test/Reference Direct Comparison (Preliminary)
July 1986-June 1987

Annual Source Energy Summary

	Source Effic. (%)	Building 1363 (MBtu)	Building 1663 (MBtu)	Building 1666 (MBtu)	Building 1667 (MBtu)	Mean Reference (MBtu)	Blast Model (MBtu)
Elec *	30%	2333	623	138	2089	950	2447
Heat	60%	3310	4748	7106	4131	5328	
Blast Normalized		3833	5498	8230	4784	6171	5572
Cool	90%	293	NA	NA	NA	NA	
Blast Normalized		340	NA	NA	NA	NA	276
Elec & Heat		5643	5370	7245	8220	6278	
Blast Normalized		6536	6219	8390	7203	7271	8019
Elec, Heat, & cooling		5937	NA	NA	NA	NA	
Blast Normalized		6875	NA	NA	NA	NA	8297

Annual Source Energy Savings

	1363 vs 1663 (MBtu)	1363 vs 1666 (MBtu)	1363 vs 1667 (MBtu)	1363 vs Mean Reference (MBtu)	Savings from Blast Model (MBtu)
Elec *	-1711	-2195	-245	-1383	3
Heat	1438	3796	821	2018	
Blast Normalized	1665	4397	951	2338	3334
Cool	NA	NA	NA	NA	
Blast Normalized	NA	NA	NA	NA	6
Elec & Heat	-273	1601	576	635	
Blast Normalized	-316	1855	667	735	3337
Elec, Heat, & cooling	NA	NA	NA	NA	
Blast Normalized	NA	NA	NA	NA	3343

Annual Source Energy Savings Per Sq. Ft.

	Floor Space (Sq.Ft.)	1363 vs 1663 (KBtu/ sq.ft.)	1363 vs 1666 (KBtu/ sq.ft.)	1363 vs 1667 (KBtu/ sq.ft.)	1363 vs Mean Ref. (KBtu/ sq.ft.)	Savings, Blast Model (KBtu/ sq.ft.)
Elec *	40698	-42.0	-53.9	-6.0	-34.0	0.07
Heat	40698	35.3	93.3	20.2	49.6	
Blast Normalized	40698	40.9	108.0	23.4	57.4	81.9
Cool	40698	NA	NA	NA	NA	
Blast Normalized	40698	NA	NA	NA	NA	0.1
Elec & Heat	40698	-6.7	39.3	14.2	15.6	
Blast Normalized	40698	-7.8	45.6	16.4	18.1	82.0
Elec, Heat, & cooling	40698	NA	NA	NA	NA	
Blast Normalized	40698	NA	NA	NA	NA	82.1

Annual Percent Savings at Energy Source

	1363 vs 1663 (%)	1363 vs 1666 (%)	1363 vs 1667 (%)	1363 vs Mean Reference (%)	Savings from Blast Model (%)
Elec *	-274.7%	-1586.7%	-11.7%	-145.6%	0.12%
Heat	30.3%	53.4%	19.9%	37.9%	
Blast Normalized	30.3%	53.4%	19.9%	37.9%	59.8%
Cool	NA	NA	NA	NA	
Blast Normalized	NA	NA	NA	NA	2.2%
Elec & Heat	-5.1%	22.1%	9.3%	10.1%	
Blast Normalized	-5.1%	22.1%	9.3%	10.1%	41.6%
Elec, Heat, & cooling	NA	NA	NA	NA	
Blast Normalized	NA	NA	NA	NA	40.3%

* From meter readings.

NOAA HDD (Fort Carson Jul 1986-April 1987; Colorado Springs May 1987-June 1987, due to availablity): 5539   Blast HDD: 6415
NOAA CDD (Fort Carson Jul 1986-April 1987; Colorado Springs May 1987-June 1987, due to availablity): 452   Blast CDD: 531

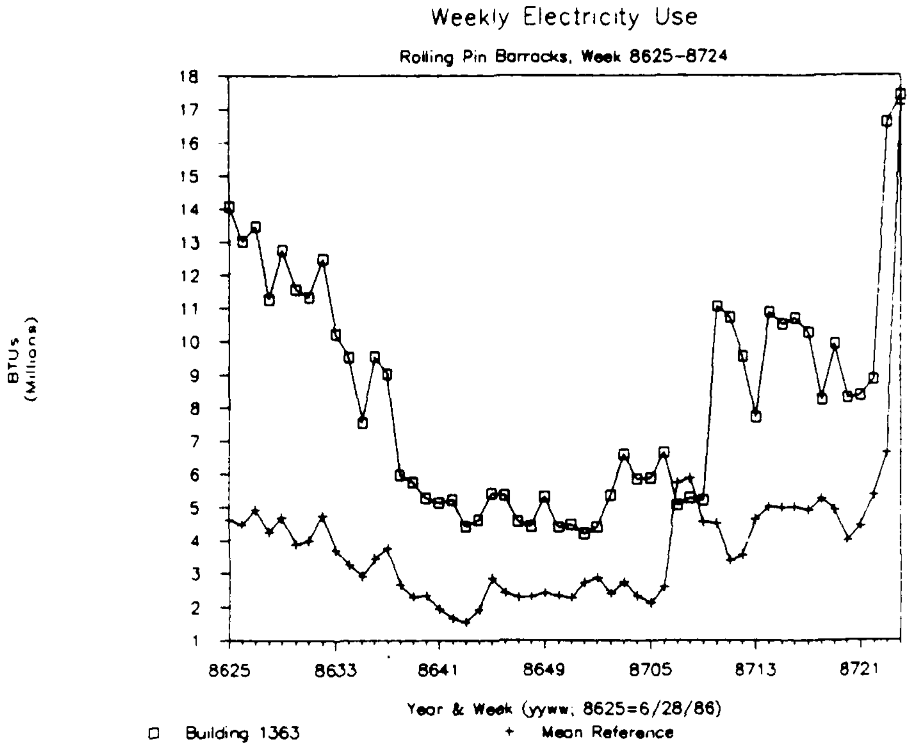

Figure 37. **W-ekly electricity use of rolling pin barracks, week 8625 - week 8724.**

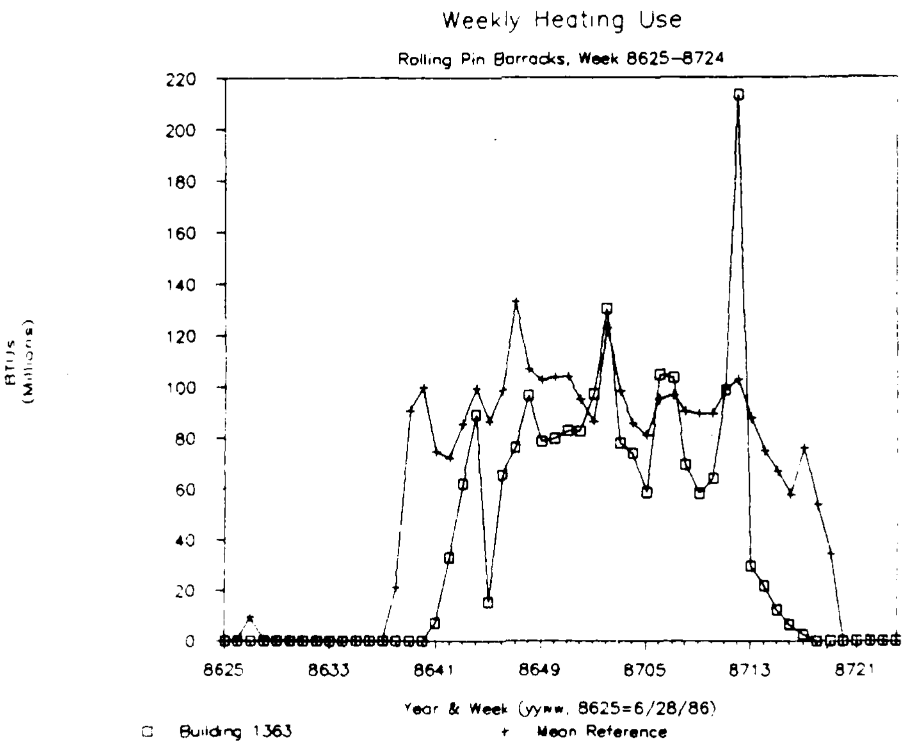

Figure 38. **Weekly heating use of rolling pin barracks, week 8625 - week 8724.**

Annual source electrical estimates from BLAST were 2447 MBtu for baseline consumption, witn savings of 3.0 MBtu, 0.07 kBtu/sq ft, or 0.12 percent of baseline consumption for the rolling pin barracks. Annual source electrical consumption based on observed data is 950 MBtu, with savings of -1383 MBtu, -34 kBtu/sq ft, or -146 percent of observed baseline.

An annual cooling energy total was available only for the test building at the time of this publication. The normalized cooling energy consumption of 340 MBtu is close to the BLAST-modeled consumption of 278 MBtu. It was anticipated that these totals would account for about 3 percent of total building energy use.

Total annual rolling pin barracks energy consumption (for heating and electricity only) at Colorado Springs was estimated by BLAST at 8019 MBtu, with a total anticipated savings of 3337 MBtu, 82 kBtu/sq ft, or 42 percent of annual baseline. All-site average BLAST projections (total building) had been for annual consumption of 7000 MBtu, with savings of 2238 MBtu, 55 kBtu/sq ft, or 32 percent of annual baseline. Observed building totals (heating and electricity only) show normalized annual energy consumption at 7271 MBtu, with a net savings of 735 MBtu, 18.1 kBtu/sq ft, or 10 percent of baseline consumption.

Insights. Observed reductions in heating consumption at the rolling pin barracks totaled 38 percent. However electrical consumption of 146 percent over mean reference consumption brought the net building savings to 10 percent. This overall savings of 10 percent was a good reduction in baseline consumption, but well below anticipated savings. Actual net Btus saved were 22 percent of that projected by BLAST. Several factors may be contributing to the differences in anticipated versus observed energy savings.

The estimates made by BLAST of annual heating consumption are in good agreement with observed average consumption. Electrical estimates were very close to values for two of the buildings monitored, but substantially different than the mean reference consumption. In both heating and electrical categories there was a wide variability in building consumptions. Data from Building 1666 is significantly different from other reference buildings. It may be that statistical review of this data will allow disqualification of Building 1666 data in future energy comparisons. Additionally, there may be other factors such as differences in occupancy or maintained interior temperature which are affecting the data.

Reduced heating savings must be attributed to the cancellation of wall insulation in this building category. Additionally, the building control system is suspect for compromising the effectiveness of the retrofits by causing overheating. Here, as in other buildings, open windows have been observed consistently during the heating season due to overheated interior spaces.

Summary

The savings in total building energy observed by direct comparison has been substantial for all building categories, ranging from 10 to 28 percent. The majority of this savings can be credited to reductions in heating consumption of 23 to 43 percent. Savings in electrical consumption were inconsistent, with results ranging between 14 and -146 percent. Cooling energy consumption, available for one building category only, showed a 1.3 percent savings. To varying degrees, all categories fell short of anticipated energy savings on both a percentage and an absolute magnitude basis.

The reasons for observed discrepancies with original calculations need to be investigated prior to passing judgment on the trial retrofit packages. Variations in energy totals is due in part to the changes made in the packages during final design and implementation, and should be compensated for. Examination of the data used to calibrate the BLAST runs may also shed light on the differences. Additionally, further data cleanup and projection refinement is appropriate.

Building characteristics such as interior temperature trends, control settings, utilization levels, maintenance conditions and openings in the building envelope appeared to have a large effect on the data. They stressed the importance of evaluating the buildings with their retrofits as integrated systems. They also pointed out the challenges in direct comparison methods.

6 FUTURE WORK

The future work on this project will include quantifying the energy saved due to retrofit packages on the test buildings and determining if the observed energy savings economically justify the retrofits.

Direct Comparison

Future efforts in the direct comparison analysis will include the continued review of the gathered data in a effort to refine it and make sense of the discrepancies between observed and anticipated results. Once confident estimates are made of the increases in energy effectiveness due to the retrofits, the cost effectiveness of chosen measures will be evaluated. A life cycle cost analysis will be made to determine the market conditions (fuel and material costs) under which the retrofits are appropriate.

Other Methods

The process of analyzing data is iterative and dynamic. Unforeseen patterns and results often prompt additional investigations. The analyses performed thus far have suggested that lack of continuity in gathered data confuses annual interpretations and that differences between buildings other than the retrofit packages may be affecting the data significantly.

Often the use of a few different methods provides combined insight which is not apparent from one method alone. Methods of data analysis other than the direct comparison approach will be explored in the future for appropriateness and feasibility. Two methods which will be considered are briefly discussed below.

Eliminating the Need for Continuous Data

This method attempts to resolve heating (or cooling) savings through the use of regression analysis. Regression analysis eliminates the need for completely continuous data since regression models only require several representative sampling periods (weekly or daily data points). The heating load of a building varies linearly with the outdoor temperature. Thus, regression lines for building load (Btus delivered) versus outdoor temperature can be calculated for both the test and combined reference buildings. Since the slope of the regression line is indicative of the thermal characteristics of the building, savings is calculated by looking at the percent change in slope.

Adjusting Data for Differences Between Buildings

The objective of this method is to estimate the difference in energy used between buildings with retrofit packages and without retrofit packages and adjust for differences in building mechanical operations and building use. Or equivalently, the objective is to quantify the mean difference in response (energy used) due to treatments (envelope changes and some control changes) between the control and test groups, with the responses being adjusted for the other factors (or treatments) which affect the response but are not part of the retrofit treatment.

The four steps of the procedure are as follows:

1. Study building data to identify regular operating conditions and pertinent parameters affecting energy use (differing conditions, malfunctioning equipment, etc.). Relationships for exploration might include:

- Relative energy use (monthly/weekly trends over time for each test building versus control buildings for gas, electric, central heating Btus, and central cooling Btus)
- Energy savings/loss graph
- Heating reset schedules for each zone
- Outside air temperature trends
- Heating loads versus outside temperature
- Pump operation versus outside temperature
- Boiler efficiency versus ambient temperature
- Boiler efficiency versus load
- Interior room temperature versus outside temperature
- Domestic hot water (DHW) temperature and flow trends
- Occupancy count trends
- Energy use versus occupancy
- Boiler cycling times.

2. Identify response variables and explanatory variables and test for significance and independence. The response variables may well be partial energy consumptions such as electrical use, gas use, heating and cooling Btus, and DHW Btus. The explanatory variables which affect the response would of course include the retrofit package (a binary variable, either present [1] or not [0]) but also include the operational and mechanical conditions of the buildings. These effects might be evidenced in such data as:

- Differential temperatures (indoor-outdoor)
- Occupancy levels
- Meals served (dining halls)
- Heating system efficiency
- DHW settings
- Reset schedules on heating loops

- Condensate levels (measure of utilization of dining halls)
- Amount of data collected (affects projected totals).

3. Run regressions for each building category, correlating the relationship between the sum of the treatments and the response. These regressions would use both test building data and control building data as input. This model, made with data from buildings with differing operations, is indicative of the building category rather than particular operational settings.

4. Using this building category model, determine the effect on response (energy used) of one particular treatment (retrofit package). This could be determined by investigating the regression coefficient of the retrofit variable.

7 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The investigation the application of theoretically optimal retrofit packages on real-world buildings has led to the following preliminary conclusions.

- All retrofit packages are saving a significant amount of energy when compared directly with nonretrofitted buildings. Whole-building savings at Fort Carson are between 10 and 28 percent. Most of the savings can be credited to reductions in heating consumption of 23 to 43 percent.

- Observed savings are less than anticipated. The reasons for the differences need to be investigated prior to passing judgment on the trial retrofit packages.

- A building needs to be investigated as a whole system. The envelope and the heating, ventilating, and air-conditioning system cannot be considered separately, because they act together to affect building operational costs. In recent years much attention has been given to conserving energy with structural improvements such as adding wall and ceiling insulation and installing storm doors and double-glazed windows. These methods of isolating the interior conditioned space from the outside cold or heat are based on sound theoretical and empirical information. However, they can save energy in Army buildings only if the buildings are operated and maintained at the levels assumed in the energy analysis calculations.

- Building operation and maintenance levels can compromise the paybacks of retrofit packages. Ongoing energy monitoring of buildings has employed extensive instrumentation which has provided insight into building operations not otherwise available. This monitoring has revealed that much potential exists to improve use and control of existing mechanical heating equipment, thus bringing the buildings up to the assumed level of readiness for commonly proposed energy conservation alternatives. Specific targets for improvement include overheated interior spaces (caused by heating controls adjustments and upkeep, and limited control capabilities), broken windows, and inefficient heat production.

- Retrofits must be not only energy effective but also functionally acceptable and reliable, physically and practically executable, and cost effective. These lessons were emphasized during retrofit application. The disabling of night setback thermostats at the motor pool and the decision against nonoperable storm windows in the barracks raised the question of the acceptability of the retrofit. The decision to replace rather than just weatherstrip broken doors at the motor pool was based on practicality. The inaccurate functioning of controls when installed in the barracks and dining hall stressed the need for reliability and acceptable maintenance requirements. The size requirements of the heat recovery system at the dining hall proved impractical. The abandonment of foam insulation at the rolling pin barracks resulted from execution concerns. The high cost of window units challenges cost effectiveness.

Overall, the lessons learned thus far in retrofit and product selection and application have been important. While some alternatives have yielded benefits more than originally credited, others have not met expectations. All retrofits are being verified with measured energy data. All lessons have furthered the knowledge needed for establishing viable retrofit packages. Preliminary results indicate that a wide-scale retrofit program may not be first priority for energy conservation given the existing conditions of the standard-design buildings. Other preparatory measures (such as improving controls) may be necessary to allow the retrofits to demonstrate their savings potential.

Recommendations

These conclusions are based on limited review of the data. Further data analysis of the energy use profiles is necessary to determine if the current retrofit packages are cost effective in existing Army buildings. This analysis should consider these issues.

- Energy use can vary widely between buildings. The causes of these variations need to be investigated to better understand the savings potential of energy retrofits.

- Complementary analysis methods should be used. The use of several methods provides combined insight not available from one method alone. Differences between buildings other than the retrofits may be significant. Thus, means are needed to quantify the savings attributable to the implemented retrofit.

- Cost scenarios (for fuel and materials) under which the retrofit packages are appropriate need to be determined.

- Computer models for retrofit decision making need to be used with care. Even standard designs are not completely identical because they are often modified to accommodate a facility's location and mission. Operations and maintenance conditions are not always as expected. At times, these differences from assumed conditions can significantly alter expected energy results. If computer models are to be used effectively, their assumptions must be substantiated prior to constructing the retrofit. The economy of computer-modeled retrofits makes them appealing alternatives to customized designs, but site surveys need to be conducted to verify buildings' materials, systems, and operation. Appropriate building-model adjustments and reruns need to be made prior to decision making.

METRIC CONVERSION FACTORS

LENGTH	1 ft.	=	.3048 m
AREA	1 ft^2.	=	.0629 m^2
PRESSURE	1 psi	=	6895 N/m^2 (Pascals)
ENERGY	1Btu	=	1024 J
	1 MBtu	=	10 E 6 Btu
	1 KBtu	=	10 E 3 Btu
	1 KWh	=	3413 Btu
	1 MBtu	=	1.055 GJ
ENERGY/AREA	1 Btu/ft^2	=	11345 J/m^2
HEAT CAPACITY (WATER)	1 Btu/1bm*F	=	1 cal/g*K
		=	4.184 J/g*K
		=	8.019 Btu/gal*F ~ 95 °F
TEMPERATURE	Kelvin = ((Fahrenheit = 32)/1.8) + 273.15		
	Celsius = (Fahrenheit = 32)/1.8		

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APPENDIX A:

DATA ACQUISITION AND INSTRUMENTATION

This appendix describes the data acquisition system used for remotely monitoring building energy usage in four types of standard design buildings at Fort Carson, CO. A total of 14 buildings are being monitored.

The energy parameters monitored (as appropriate for each system) are room, water, and outdoor temperature; flow of heating hot water, domestic hot water, cooling water, and steam condensate; and building gas and electric usage. Tables A1 through A4 show the energy inputs and the associated instrumentation for each type of building. Data aquisition units (DAUs) are used to measure and digitally record these parameters.

Information stored by the DAUs is remotely accessible via telephone lines. This data is downloaded to microcomputers at USA-CERL twice a week for analysis. In addition, the DAUs are called daily by local computers and the status of the instrumentation is printed in a log report.

This appendix is intended for a system designer or operator and thus contains detailed information on the hardware and procedures used to accomplish the energy monitoring goal. It is organized into the following sections: (1) an overview of the data acquisition system, including a brief description of the equipment used, the system configuration, the data gathering scheme, and the system support involved; (2) specifics on the sensors used, including the DAU (its operation, programming and accuracy), the temperature sensors, the flow meters, and the electric and gas meters; and (3) guidelines on system troubleshooting.

References to manufacturers are made to fully identify the equipment used in this project. They are not endorsements of the products. Several other manufacturers also provide similar and acceptable equipment.

Table A1

Signals Monitored at the Motor Vehicle Repair Shops

Buildings 633, 634, 635, 636

Energy Parameter	Metering	Instrument	Signal
GAS supplies steam boiler which services building unit heaters	Meter at main service	Rockwell Model 1000 gas meter with pulse initiator.	Contact Closure
ELECTRIC lighting, power	Meter at main service	General Electric watthour meter with pulse initiator	Contact Closure
BUILDING CONDITIONS	Room Temp -bay area -office area	Hy-cal 32 - 122 CT & 100 ohm platinum RTD	4 to 20 mA

Table A2

Signals Monitored at the L-Shaped (Type 64) Barracks

Buildings 811, 812, 813

Energy Parameter	Metering	Instrument	Signal
GAS supplies 2 steam boilers for heating & DHW and a direct fired DHW heater.	Meter at main service	Rockwell Model 5000' gas meter with pulse initiator.	Contact Closure
ELECTRIC lighting, power, ventilation	Meter at main service	General Electric watthour meter with pulse initiator	Contact Closure
BUILDING CONDITIONS	Outdoor Temp	Hy-cal -50-150 CT & 100 ohm platinum RTD	4 to 20 mA
	Room Temp -1st floor east -1st floor west -2nd floor east -2nd floor west -3rd floor east -3rd floor west -south zone	Hy-cal 32-122 CT & 100 ohm platinum RTD	4 to 20 mA
HEATING BTUS steam services hot water loop for fin tube radiators on three zones.	Water Temp -zone 1 supply -zone 1 return	Hy-cal 0-250 CT & 100 ohm platinum RTD	4 to 20 mA
	Water Flow -zone 1	Viatran 0-5 psi PT & Barco 1.5" Venturi	4 to 20 mA
	Water Temp -zone 2 supply -zone 2 return	Hy-cal 0-250 CT & 100 ohm platinum RTD	4 to 20 mA
	Water Flow -zone 2	Viatran 0-5 psi PT & Barco 3" Venturi	4 to 20 mA
	Water Temp -zone 3 supply -zone 3 return	Hy-cal 0-250 CT & 100 ohm platinum RTD	4 to 20 mA
	Water Flow -zone 3	Viatran 0-5 psi PT & Barco 3" Venturi	4 to 20 mA
COOLING BTUS child water from central plant circulates to fan/coil units.	Water Temp -child wtr sup -child wtr ret	Hy-cal 0-250 CT & 100 ohm platinum RTD	4 to 20 mA
	Water Flow -child water	Viatran 0-5 psi PT & Barco 3" Venturi	4 to 20 mA
DOMESTIC HOT WATER BTUS direct fired DHW heater in conjunction with a steam boiler provide dom. hot wat.	Water Temp -cold wtr feed -dom. hot wtr	Hy-cal 0-250 CT & 100 ohm platinum RTD	4 to 20 mA
	Water Flow -cold water for domestic hot water	Badger flow meter with pulse initator	Contact Closure

Table A3

Signals Monitored at the Dining Hall

Buildings 1361, 1369, 1669

Energy Parameter	Metering	Instrument	Signal
GAS supplies fuel for kitchen cooking equip.	Meter at main service	Rockwell Model 5000 gas meter with pulse initiator.	Contact Closure
ELECTRIC lighting, power	Meter at main service	General Electric watthour meter with pulse initiator	Contact Closure
BUILDING CONDITIONS	Room Temperature	Hycal 32-122 CT & 100 ohm Platinum RTD	4-20 ma
HEATING BTUS high temp. hot water from a central plant services low temp hot water loop for heating.	Water Temp -H W supply -H W return	Hycal 0-250 CT & 100 ohm Platinum RTD	4-20 ma
	Water Flow -heating	Viatran 0-5 psi PT & Barco 3" Venturi	4-20 ma
KITCHEN EQUIPMENT high temp hot water from a central plant is supplied to a steam converter for kitchen equipment.	Water Flow -Condensate	Badger flow meter with pulse initator	Contact Closure
DOMESTIC HOT WATER BTUS high temp. hot water supplies heat exchanger for domestic hot water.	Water Temp -Cold water feed	Hycal 0-250 CT & 100 ohm Platinum RTD	4-20 ma
	Water Flow -Cold wtr feed	Badger flow meter with pulse initator	Contact Closure

Table A4

Signals Monitored at the Rolling Pin Barracks

Buildings 1363, 1663, 1666, 1667

Energy Parameter	Metering	Instrument	Signal
ELECTRIC lighting, power, ventilation.	Meter at main service	General Electric watthour meter with pulse initiator	Contact Closure
BUILDING CONDITIONS	Room Temp -1st floor -2nd floor -3rd floor	Hycal 32-122 CT & 100 ohm Platinum RTD	4-20 mA
HEATING BTUS high temp hot water from a central plant services low temp hot water for heating.	Water Temp -H W supply -H W return Water Flow -heating	Hycal 0-250 CT & 100 ohm Platinum RTD Viatran 0-10 psi PT & Barco 3" Venturi	4-20 mA 4-20 mA
COOLING BTUS child water from a central plant circulates to air handler units.	Water Temp -child wtr sup -child wtr ret Water Flow -cooling	Hycal 0-250 CT & 100 ohm Platinum RTD Viatran 0-5 psi PT & Barco 4" Venturi	4-20 mA 4-20 mA
DOMESTIC HOT WATER BTUS high temp hot water from a central plant supplies heat exchanger for domestic hot water.	Water Temp -cold wtr feed Water Flow -cold wtr feed	Hycal 0-250 CT & & Platinum RTD Badger flow meter with pulse initiator	4-20 mA Contact closure

System Overview

Equipment

Datalogger. The Acurex Autograph 800 data acquisition system is the data recording unit for this project. It was chosen mainly for its remote programming capabilities, but its other desirable features are diversity of accepted input, local data manipulation capability, data storage, and online printer. The remote capabilities allow the researchers to view and check real time information, program and reprogram information processing, and transfer stored data. The unit accepts up to 256 programmed channels for analog or digital input or mathematical processing. It will perform scaling, averaging, and logical functions on data. Its 256K (expandable to 512K) history file card stores data in RAM in compressed ASCII format. Additionally, the Autograph 800's online thermal printer provides hard copy printout for on-site information retrieval and RAM backup.

Instruments. A variety of instruments in each building supply input signals to the DAUs. Fourteen General Electric kilowatt-hour meters and 10 Rockwell gas meters provide contact closure pulses to the Autograph for totaling electricity and gas usage. Twenty-three Aeroquip venturis in water lines produce a differential pressure which is converted by Viatran pressure transducers to a 4 to 20 mA signal for flow measurement. Thirteen Badger positive displacement flow meters output contact closure pulses for water metering. More than 100 Hy-Cal resistance temperature detectors (RTDs) with current transmitters provide 4 to 20 mA signals which indicate water temperature in pipes, and indoor and outdoor ambient temperatures. Tables A1 through A4 give details of the instrumentation and signals generated.

Modems. Microcom SX/1200 modems are used to communicate remotely via telephone lines with the Autograph from an IBM-AT at USA-CERL. These 1200-baud modems use an error-checking protocol which verifies the data transmitted and initiates a retransmission of information upon detection of an error. Experience has revealed the acute need for error detection on noisy phone lines, which are common on Army installations and over long distances. Data transfer over Federal Telephone Service (FTS) lines without error checking has yielded garbage filled and even unprocessable (non-ASCII) files. Since the Autograph does not run an error checking program, an external device with this feature is essential, hence the Microcom modem. Table A5 shows the modem configurations used with this project.

Personal Computers. Two microcomputers are used at USA-CERL to suport the data acquisition and analysis effort. One computer, used for data collection and initial analysis, is a standard IBM-AT with 20 megabytes of hard disk storage, 1.5 megabytes of RAM, and running at 6 MHz. The other computer, used for detailed analysis, is an IBM-AT upgraded to use the Intel 80386 processor running at 16 MHz, Intel 80287 math coprocessor running at 10 MHz, 3.2 megabyte of RAM, approximately 90 megabytes of hard disk storage, and 69 megabyte of 1/4-in. streaming tape backup. Both machines are used only for this project.

The IBM-AT receives history files from the Autograph and runs the Symphony, BASIC, and Statistical Package for the Social Sciences (SPSS) software used for data manipulations. The Alloy 1/4-in. streaming tape drive provides backup and archive facilities for the energy data. A compiled BASIC program coordinates the communications and file processing routines.

Table A5

Modem Settings for ECRSD Project

Switch 1	up	Use Xon/Xoff flow control
Switch 2	down	
Switch 3	down	Auto answer and error checking on
Switch 4	down	
Switch 5	up	Not Used
Switch 6	down	Baud Rate = 1200
Switch 7	up	
Switch 8	up	

System Configuration

Location. The energy monitoring instruments and the Autograph 800 data acquisition systems are located in the mechanical rooms of the buildings. One Autograph serves one building, except for the vehicle repair shops, where one Autograph receives hard-wired signals from four buildings via cables affixed to nearby telephone poles. A total of 11 Autographs are in use.

The energy monitoring instrumentation is suited for the rugged conditions in the mechanical rooms. Although this setting pushes the limits of the DAUs' environmental specifications, the location has definite advantages. The Autograph is close to the instruments it monitors, which makes it easier to trace wiring schemes and calibrate units. The arrangement allows an almost one-stop field inspection at each building. Furthermore, it keeps the equipment out of sight and hearing of building occupants.

Cabinets. A locked, steel-rack cabinet houses each Autograph (Figures A1 and A2). The cabinet's sliders hold the Autograph and modem off the floor and out of danger from mechanical room flooding. The doors of the cabinet conceal the front panel keyboard and fluorescent display from would-be investigators. The cabinet also serves as a mounting surface for telephone jacks and cable connections and as storage space for extra paper and a few tools.

Cabling. Signal cables from the various instruments are brought to terminal blocks in a wall panel (Figure A3). Wiring from the wall panel is then brought to the cabinet containing the Autograph. Inside the cabinet the signal cable is terminated with a DB-25 connector whose mating connector is attached to a short "pigtail" run of signal cable from the Autograph input cards (Figure A4). This cabling scheme between instrument and Autograph provides two benefits. First, it simplifies the thorough checkout for accuracy and safety of instrument signals prior to connecting them to the Autograph.

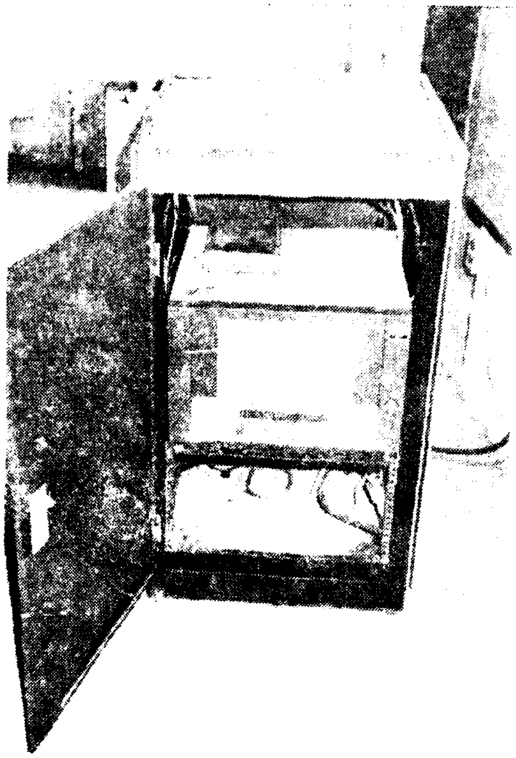

Figure A1. Front view of datalogger in cabinet.

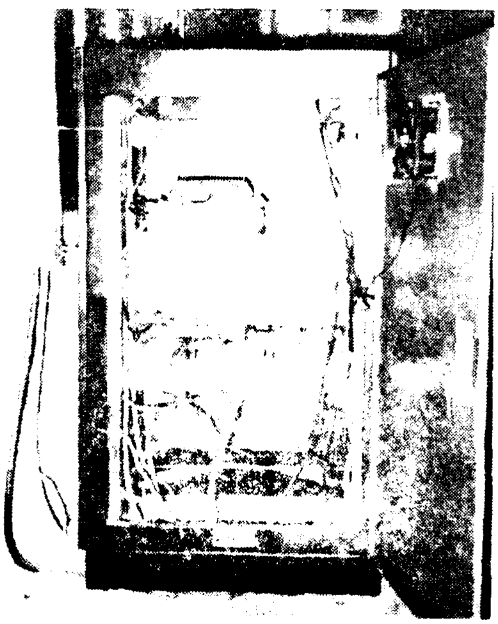

Figure A2. Rear view of datalogger in cabinet.

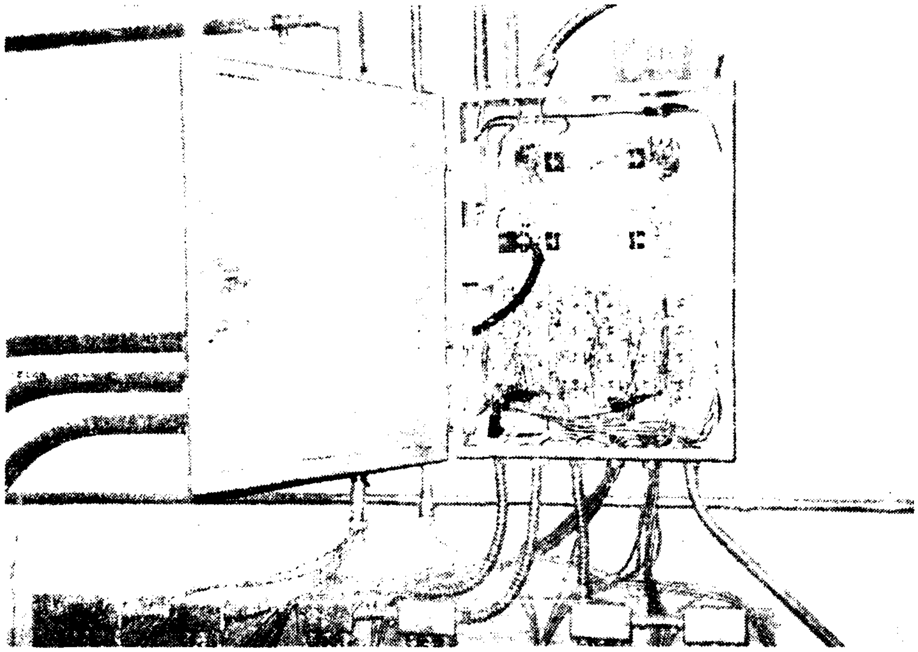

Figure A3. Wall panel at L-shaped barracks.

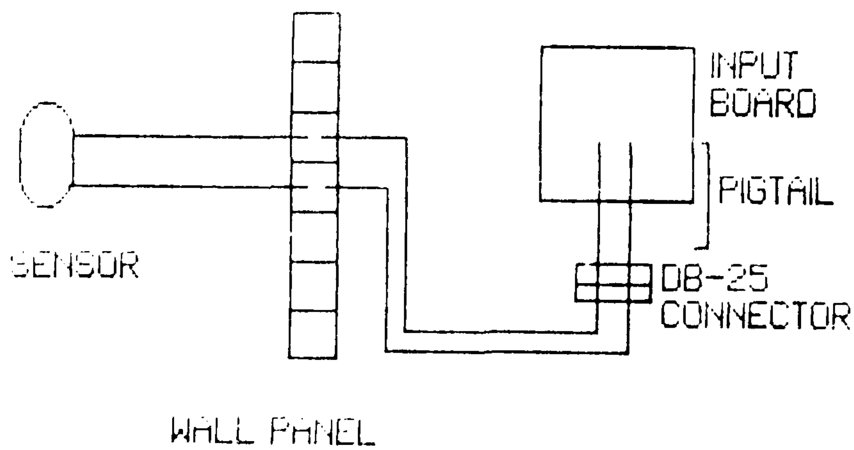

Figure A4. Cabling scheme.

Second, since the short pigtails wired to the DAU input cards are connected prior to shipping, it minimizes the field wiring needed after the first installation of the Autograph should an input card or an entire DAU need replacing. All wires are looped prior to connecting them to input cards on the Autograph to prevent any condensation on the cable casing from running into the Autograph circuitry. Spare pairs of cable were installed with the wiring between wall panel and Autograph to provide for potential expansion or possible cable breakage.

Shielding. Signal cables are 22-gauge, stranded, individually-shielded, twisted pairs in 10-pair bundles. Shields running in a continuous path from sensor to Autograph are tied together at the Autograph and connected to the chassis ground. Shields are left unconnected at sensors to prevent ground loops. Although shielded cable is not generally required for current signals, it was chosen for all applications due to the electrically noisy environment of the mechanical rooms and the use of contact closure signals adjacent to current lines.

Heat. Temperatures near and above 100 °F are not uncommon in the mechanical rooms of the demonstration buildings. The Autograph environmental rating is 120 °F and the modem rating is 105 °F. Fans are installed in the rack cabinets to dissipate the heat generated inside the cabinet.

Power. Power line failures can cause loss of data. Power line surges and equipment-generated noise can cause malfunction or failure of a DAU. The data stored in the Autograph is safeguarded with a battery backup in the Autograph mainframe which can withstand a 4-hour power outage. The power line to the Autograph is protected in four places. A fuse is located near the service entrance to the building. Circuit breakers are contained in the outlet strip affixed to the rack cabinet and at the on/off switch at the Autograph. The wall outlet inside the locked wall panel has an Archer broadband noise filter and voltage spike protector.

However, even with these measures, lightning strike damage has occurred. Further investigation is needed on lightning protection.

Systems Support

Field Help. Although minimal human intervention is desired, the benefit of visual inspection of system operation is hard to replace. The 1000-mile telephone link between investigator and project makes it difficult to sustain desired system performance. While plans are underway to increase uptime, a field technician has been hired to help support the 11 systems. The field technician's duties include cycling power to the DAUs if needed, changing printer paper, cleaning dusty fan screens, maintaining cabling, replacing failed electronics, calibrating equipment, relaying site information, and investigating and reporting any anomalies.

Documentation. Substantial documentation is required to remotely maintain a system of this size and complexity. Careful logging of equipment location, serial numbers, warranty codes, firmware revisions, and purchase and service dates has proven essential for manufacturer support. Detailed records of equipment layout, instrumentation ranges, cabling and shielding schematics, computer interface parameters, along with well-documented program code, data format schemes, and observations on system performance have been invaluable for remote troubleshooting between site visits.

Software. Daily communication with the Autograph systems has taken place to maintain data quality. This previously labor-intensive procedure is now performed by software running on the IBM-AT. A BASIC program automatically calls up each building, gets a paper printout of real time information, dumps and resets history files, check signals, and preprocesses and enters data into Symphony for analysis. Details of this program are found in Appendix B.

Several error trapping routines sift through the data and help to flag data problems. These errors are discussed in Chapter 4: Data Quality Assurance.

Data Gathering Scheme

The Autograph samples the milliamp input signals once each minute and monitors the contact closure signals continuously. The milliamp signals are digitized and scaled and a running total of the scaled contact closures is updated. This information is used in minute-by-minute zone Btu calculations. All minute information is stored in a history file which holds a day's worth of minute data and overwrites itself daily. Each hour, the information from the past sixty minutes is averaged or totaled and stored in a second history file which holds up to 3 weeks of hourly information. Hourly statistics of the minute data (such as number of samples and information for computing standard deviations) are also stored (Figure A5). The hourly history data is routinely transferred to USA-CERL. Minute data is only transferred when greater resolution of energy information is desired. This two-file scheme captures the benefit of frequent sampling without the related data-crunching effort and makes the minute information available if needed.

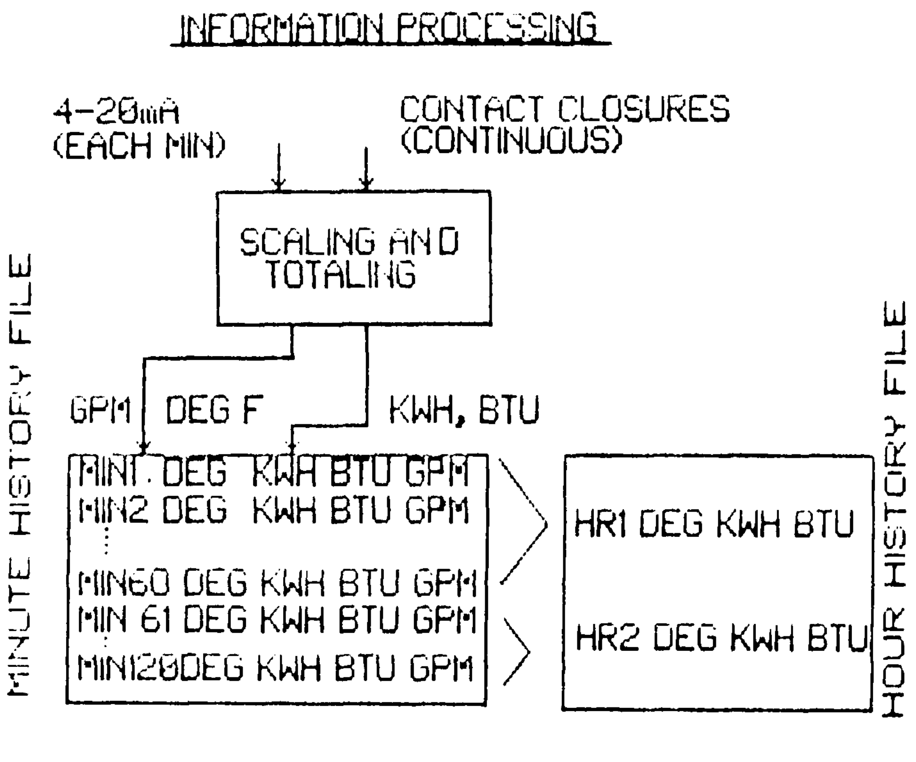

Figure A5. Information processing.

Specifics of Instrumentation and Operation

Acurex Autograph 800 Datalogger

Description. Information from the instruments is recorded by the Acurex Autograph 800 datalogger. The Autograph is a multipoint DAU capable of accepting a variety of input signals. It can sample up to 256 channels with 60 on-board analog channels and 30 pulsed channels.

The Autographs contain several circuit boards which the systems operator must know about to maintain the system. Among these are the:

- netpac controller
- central processing unit (CPU)
- analog input card (volt/thermocouple/milliamp)
- pulse input board
- printer controller
- history file card
- power supply assembly.

There is also a battery and battery charger to provide program and data protection against power failure. The netpac controller is an intelligent digital volt meter controlled by a microprocessor. The analog input card is a two-piece board that contains the input terminals for hardwiring the incoming signals (on one end) and a bank of 20 relays (on the other end) that are used to multiplex the 20 signals for the netpac. The printer controller governs the thermal printer. The history card is a board that contains 256K of RAM that is used for data storage. The CPU controls all the boards in the Autograph. This is also where the Autograph program is stored.

Programming. The Autograph is programmed by entering instructions in up to 256 memory registers. It sequentially executes these instructions upon each programmed scan cycle. The Autograph can be programmed two ways: by the front panel or remotely. Front panel programming consists of stepping though a series of question loops grouped under eight function headings on a 32-character fluorescent display. A valid response from a menu of answers brings up the next question. Examination of the flow charts in the operator's manual coupled with trial and error allows the programmer to answer only the questions necessary to achieve the desired result, thus speeding up programming time. The data gathering and processing program can be secured with a password option.

Remote programming consists of an abbreviated form of local programming with one and two letter mnemonics strung together in precise lines without comments. The code is difficult to master unless the user thoroughly understands front panel programming, since a few quirks in remote interfacing are undocumented. Certain commands will crash if the command is not in a specific position relative to other commands. Additional command errors will be flagged if trailing spaces at the end of some command lines are not removed. Uppercase commands should be used because the Autograph will accept but not act on a handful of possible commands if they are given in lowercase, while other commands given in lowercase are processed without problem.

The key to rapid remote programming is batch processing. Highly commented code is created using the text editor on the IBM-AT. A BASIC program strips the comments and trailing spaces off the commented file and creates an Autograph-ready file. This file is sent to the Autograph using the Remote Data Acquisition Support System (see Appendix B) developed at USA-CERL. The program can be resent or edited without extensive retyping. Remote programming is substantially faster to enter and easier to modify or correct than front panel programming. Figure A6 is an example of an Autograph batch program. This program was used in building 1361.

Several standard data manipulation schemes (averaging, standard deviations, graphing, logic) have default programming or function calls available. Fairly specialized data crunching (date in a data column, automatic resetting of data fields) can be achieved by manipulating channel registers with algorithms similar to assembly language programming.

The operating system of the Autograph does not allow complete programming flexibility but does provide for most needed options. Where USA-CERL has advised the manufacturer of oversights in options revised firmware has been provided. To accommodate the needs of this project, the current version of firmware allows remote monitoring of history file programming and history file free space available, remote capabilities for aborting a history file dump, and a programmable time out value, which extended the wait time from 10 to 120 seconds before serial port timeouts to allow time for the receiving equipment to process incoming data and allow the Microcom modems time for retransmitting data.

Remote Communication. The successful communication between datalogger and personal computer requires meticulous attention to interface protocol. The Autograph uses the RS-232C serial port interface to transfer ASCII-coded files to compatible devices. It supports hardware flow control only, and its default configuration is a seven-bit word length with two stop bits and no parity at 1200 baud. Connecting devices are matched to these parameters for best results. Although interface parameters can be changed on the Autograph, an unexpected clearing of memory resets the communication port to default settings, and thus can result in a remote communications block until front panel programming reconfigures the serial port.

During remote communications, the Autograph does not buffer data gathering if communication delays occur when modem or microcomputer buffers fill up, but rather suspends scanning until a clear-to-send signal is received from the modem. If the modem fails to send a go-ahead signal within the specified number of seconds of its initial time out, the Autograph resumes processing of information and directs it to local ports only. Information processed between the time limit and the modem go-ahead signal is lost to the remote observer. In inital efforts, the time limit was reached and information was lost in transmission when data was processed simultaneously while it was being received at the IBM-AT. The holdup was discovered to be the slowness of the interpreted BASIC programming. A compiled version of the same program processed information within the time constraints of the system.

Signal Scaling. Raw input signals from the various instruments are sensed by the Autograph and converted to engineering units appropriate for the measured process. Temperatures are converted to degrees Fahrenheit, flow to gallons per hour, energy total to Btus or kWhs. Table A6 contains a list of the scaling equations used.

Listing 1. Sample Autograph Program Used At Building 1361

```
==========================================================================================================
SN2,C0/100,I00:01:00,SEY                                        !MIN SCAN
SN1,C31/63,I01:00:00,SEY,EC8                                    !HR AVG SCAN
C0,EU25,EX[022286]                                              !START DATE IN FORM MO-DA-YR
C1,EU26,EX[1361.63],UNBLDG                                      !BLDG #
C2,EU21,L01/00/00,MX2,UNDEGF                                    !ROOM TEMP MESS HALL, DEGF, MIN SCAN
C3/5,EU21,L01/00/01,MX1,UNDEGF                                  !TEMP HW SUP, DEGF, MIN SCAN
                                                                !TEMP HW RET, DEGF, MIN SCAN
                                                                !TEMP CW FEED FOR DHW, DEGF, MIN SCAN
C6,EU21,L01/00/04,MX4,EX[100*SQR(CN/70)],UNGAL,L1/5             !WTR FL HW SUP, GAL, THIS MIN
C1/6,IC2/1,IC4/1
C7,EU25,EX[TIM],L1/2                                            !SEC SINCE MIDNITE
C8,EU25,EX[CN+1-C8L1],L1/3                                      !TOGGLE FOR DATE SETTINGS
C9,EU27,EX[8.203]                                               !CONST-SPEC HT @ CONST P*RHO @ 140F, BTU/(DEGF*GAL)
C10,EU27,EX[130]                                                !CONST - DHW TEMP, DEGF
C11,EU27,EX[7756.19]                                            !CONST - HEAT OF VAPORIZATION, STEAM, BTU/GAL
C14,EU47,MX7,EX[DIG(0,0,5)],UNGAL,L1/4                          !WTR FL CW FEED FOR DHW, GAL, THIS MIN
C15,EU47,MX7,EX[DIG(0,1,5)],UNGAL,L1/4                          !WTR FL COND RET, GAL, THIS MIN
C16,EU47,MX8,EX[DIG(0,2,5)],UNKWH,L1/4                          !ELEC USE, KWH, THIS MIN
C17,EU47,MX6,EX[DIG(0,3,5)],L1/4                                !GAS USE, BTU, THIS MIN
C18,EU25,EX[(C3-C4)*C6*C9]                                      !BTU HEATING, THIS MIN
C19,EU25,EX[C11*C15]                                            !BTU STEAM IN KITCHEN, THIS MIN
C20,EU25,EX[(C10-C5)*C14*C9]                                    !BTU DHW, THIS MIN
C14/20,IC2/7,IC4/7
C17/20,UNBTU
C28,EU21,L01/00/05,MX5,IC2/14,IC4/14                            !TEMP AT AUTOGRAPH, DEGF, THIS MIN
C29,EU25,EX[CN+C7L1*100+C0*(1-C8L1)],IC2/15,IC4/15,UNDATE       !CURRENT DATE

C31,EU26,EX[C1],UNBLDG                                          !BLDG #
C32,EU25,EX[CN*(1-C100L1)+C72*C100L1/C100]                      !ROOM TEMP, MESS HALL, AVG DEGF, LAST HR
C33,EU25,EX[CN*(1-C100L1)+C73*C100L1/C100]                      !WTR TEMP HW SUP, AVG DEGF, LAST HR
C34,EU25,EX[CN*(1-C100L1)+C74*C100L1/C100]                      !WTR TEMP HW RET, AVG DEGF, LAST HR
C35,EU25,EX[CN*(1-C100L1)+C75*C100L1/C100]                      !WTR TEMP CW FEED FOR DHW, TOT GAL, LAST HR
C32/35,UNDEGF
C36,EU25,EX[CN*(1-C100L1)+C76*C100L1],UNGAL                     !WTR FL HW SUP, TOT GAL, LAST HR
C31/36,IC1/1,IC3/1
C44,EU25,EX[CN*(1-C100L1)+C77*C100L1],UNGAL                     !WTR FL CW FEED FOR DHW, TOT GAL, LAST HR
C45,EU25,EX[CN*(1-C100L1)+C78*C100L1],UNGAL                     !WTR FL COND RET, TOT GAL, LAST HR

C46,EU29,EX[CN*(1-C100L1)+C79*C100L1],UNKWH                     !ELEC USE, TOT KWH, LAST HR
C47,EU29,EX[CN*(1-C100L1)+C80*C100L1],UNMIN                     !ELEC USE, MIN ()0, LAST HR
C48,EU29,EX[CN*(1-C100L1)+C81*C100L1],UNKWH2                    !ELEC USE, TOT KWH^2, LAST HR
C49,EU29,EX[CN*(1-C100L1)+C82*C100L1/1000],UNBTU                !GAS USE, TOT BTU/1000, LAST HR
C50,EU29,EX[CN*(1-C100L1)+C83*C100L1],UNMIN                     !GAS USE, MIN ()0, LAST HR
C51,EU29,EX[CN*(1-C100L1)+C84*C100L1/1E+6],UNBTU2               !GAS USE, TOT BTU^2/1E+6, LAST HR
C52,EU29,EX[CN*(1-C100L1)+C85*C100L1/1000],UNBTU                !BTU HEATING, TOT BTU/1000, LAST HR
C53,EU29,EX[CN*(1-C100L1)+C86*C100L1],UNMIN                     !BTU HEATING, MIN ()0, LAST HR
C54,EU29,EX[CN*(1-C100L1)+C87*C100L1/1E+6],UNBTU2               !BTU HEATING, TOT BTU^2/1E+6, LAST HR
C55,EU29,EX[CN*(1-C100L1)+C88*C100L1/1000],UNBTU                !BTU/1000 STEAM IN KITCHEN, LAST HR
C56,EU29,EX[CN*(1-C100L1)+C89*C100L1],UNMIN                     !MIN () 0  IN KITCHEN, LAST HR
C57,EU29,EX[CN*(1-C100L1)+C90*C100L1/1E+6],UNBTU2               !BTU^2/1E+6 STEAM IN KITCHEN, LAST HR
C58,EU29,EX[CN*(1-C100L1)+C91*C100L1/1000],UNBTU                !BTU/1000 DHW, LAST HR
C59,EU29,EX[CN*(1-C100L1)+C92*C100L1],UNMIN                     !MIN ()0, LAST HR
C60,EU29,EX[CN*(1-C100L1)+C93*C100L1/1E+6],UNBTU2               !BTU^2/1E+6 DHW, LAST HR

C61,EU25,EX[CN*(1-C100L1)+C94*C100L1/C100]                      !TEMP AT AUTOGRAPH, AVG DEGF, LAST HR
C62,EU25,EX[C100],UNCNT                                         !COUNT OF VALUES USED FOR TOTALS
C63,EU25,EX[C29],UNDATE                                         !DATE
C44/63,IC1/7,IC3/7
```

Figure A6. Sample Autograph program used at building 1361.

```
C72,EU25,EX[CN*(1-C100L1)+C02]                  !RUNNING TOTS
C73,EU25,EX[CN*(1-C100L1)+C03]                  !RUNNING TOTS
C74,EU25,EX[CN*(1-C100L1)+C04]                  !RUNNING TOTS
C75,EU25,EX[CN*(1-C100L1)+C05]                  !RUNNING TOTS
C76,EU25,EX[CN*(1-C100L1)+C6*C6L1]              !RUNNING TOTS FLOW HEAT
C77,EU25,EX[CN*(1-C100L1)+C14*C14L1]            !RUNNING TOTS FLOW DHW
C78,EU25,EX[CN*(1-C100L1)+C15*C15L1]            !RUNNING TOTS FLOW STEAM

C79,EU25,EX[CN*(1-C100L1)+C16*C16L1]            !RUNNING TOTS ELECTRIC
C80,EU25,EX[CN*(1-C100L1)+C16L1]                !RUNNING TOTS
C81,EU25,EX[CN*(1-C100L1)+C16*C16*C16L1]        !RUNNING TOTS
C82,EU25,EX[CN*(1-C100L1)+C17*C17L1]            !RUNNING TOTS GAS
C83,EU25,EX[CN*(1-C100L1)+C17L1]                !RUNNING TOTS
C84,EU25,EX[CN*(1-C100L1)+C17*C17*C17L1]        !RUNNING TOTS
C85,EU25,EX[CN*(1-C100L1)+C18*C6L1]             !RUNNING TOTS BTU HEAT
C86,EU25,EX[CN*(1-C100L1)+C6L1]                 !RUNNING TOTS
C87,EU25,EX[CN*(1-C100L1)+C18*C18*C6L1]         !RUNNING TOTS
C88,EU25,EX[CN*(1-C100L1)+C19*C15L1]            !RUNNING TOTS BTU STEAM
C89,EU25,EX[CN*(1-C100L1)+C15L1]                !RUNNING TOTS
C90,EU25,EX[CN*(1-C100L1)+C19*C19*C15L1]        !RUNNING TOTS
C91,EU25,EX[CN*(1-C100L1)+C20*C14L1]            !RUNNING TOTS BTU DHW
C92,EU25,EX[CN*(1-C100L1)+C14L1]                !RUNNING TOTS
C93,EU25,EX[CN*(1-C100L1)+C20*C20*C14L1]        !RUNNING TOTS
C94,EU25,EX[CN*(1-C100L1)+C28]                  !RUNNING TOTS AUTOGRAPH TEMP

C100,EU25,EX[(C100+1)*(1-C100L1)+C100L1],L1/1   !COUNTER 1 TO 60
AEY                                             !ALARM ENABLE
AAN                                             !AUDIO ALARM DISABLED
L1/60H                                          !LIMIT#1=60MIN HIGH
L2/60L                                          ! ( 60 SEC SINCE MIDNITE
L3/2H                                           ! SCANED MORE THAN ONCE
L4/.0001H                                       ! BTU ( 0 -) 0
L5/15H                                          ! FLOW ( 15 -) 0
MX01,M2.5                                       !CONVERT % -) 0-250 F
MX02,M.9,B32                                    !CONVERT % -) 32-122 F
MX03,M2,B-50                                    !CONVERT % -) -50-150 F
MX04,M1.384                                     !CONVERT % -) INCHES WTR 0-5 PSI
MX05,M1.5,B-25                                  !CONVERT % -) -25-125 F
MX06,M10300                                     !CONVERT PULSES -) BTU
MX07,M.0667                                     !CONVERT PULSES -) GAL
MX08,M.024                                      !CONVERT PULSES -) KWH
MX09,M2.768                                     !CONVERT % -) INCHES WTR 0-10 PSI
MX10,M.5                                        !CONVERT % -) INCHES WTR 0-50 "WC
HF2,DS2,DR5,S75000,WRY,IDY                      !HIST FILE2-MIN SCAN INFO LAST FEW HRS
HF3,DS2,DR1,S500,WRY,IDY                        !HIST FILE3-SINGLE MIN DATA
HF1,DS1,DR1,S175000,WRN,IDY                     !HIST FILE1-HR AVGS AND HR TOTS
DS1,OD0/P,SLY,CFE,CNY,HHCERL ECRSD B1361 R6.3 HR    !SCAN 1 OUTPUT TO MODEM
DS2,OD0,SLY,CFE,CNY,HHCERL ECRSD B1361 R6.3 MIN     !SCAN 2 TO MODEM
DS3,OD0,SLY,CFA,CNY                             !HF OUTPUT MIN
DS4,OD0,SLY,CFA,CNY                             !HF OUTPUT HR
CDN                                             !THIS STATEMENT MUST GO HERE
DS5,OD/0                                        !SUMMARIES OUTPUT TO PRINTER AND MODEM
SP0,FTP,TV100                                   !SERIAL PORT TIME OUT=100SEC
```

Figure A6. (Cont'd)

Table A6

Autograph Scaling Equations

Temperature	
0-250 F	F = (% span)(2.5)
-50-150 F	F = (% span)(2)-50
32-122 F	F = (% span)(.9)+32
Pressure	
0-5 psi	P = (% span)(1.384)
0-10 psi	P = (% span)(2.768)
0-50 w.c.	P = (% span)(.5)
Pulsed Channels	
Electric	KWH = pulses * .024
gas	BTU = pulses * 10300
Flow	GAL = pulses * .0667
Flow(venturis)	
1.5"	gpm = 10 * SQRT(wc/15)
3"	gpm = 100 * SQRT(wc/70)
4"	gpm = 19 * SQRT(wc)

Analog inputs for this project are 4 to 20 mA signals which indicate temperature or flow readings. The Autograph reads the current signal as a voltage across a 25-ohm input resistor, interprets it as a percent of the span* current reading, and converts it to the final units with user-programmed scaling equations. Up to two sequential scalings can be performed on input signals with one channel. First priority is a linear equation specified in an (mx + b) form followed by a second linear or nonlinear equation manipulation which can address other channels if necessary.

---

*4 mA is 0 percent of span; 20 mA is 100 percent of span. Span is the algebraic difference between the end points of the range, here, 16 mA. Range is the measured values over which a transducer is intended to measure, specified by its upper and lower limits, here, 4-20 mA. From Harry N. Norton, *Handbook of Transducers for Electronic Measuring Systems* (Prentice-Hall, Inc., Englewood Cliffs, NJ, 1969).

As an example of the scaling process, a 0 to 250 °F RTD/current transmitter combination would output 4 mA at 0 °F and 20 mA at 250 °F. Between the extremes the output would be directly proportional to the input. Thus, if this element sensed a 100 °F condition, it would output 10.4 mA to the datalogger. The Autograph would convert this 10.4 mA to a percent span reading for the 4 to 20 mA range (100 to 500 mV range across the resistor) or (10.4 - 4)/16 = 40 percent of span. Here 10.4 is the reading, 4 is the low end of the scale (or offset), and 16 is the span for the given range. This percent of span reading would then be input for the linear scaling equation listed in Table A6. In this case, it would be multiplied by 2.5 with no offset: 40 percent x 2.5 °F/90 span = 100 °F.

Another example would be a 4 to 20 mA signal from a pressure transducer. Here this signal would be interpreted as percent of span reading, scaled linearly into inches of water column with the (mx + b) equation, then scaled nonlinearly into gallons per minute with the venturi-specific flow equations.

The digital inputs for this projects are contact closure pulses which are indicative of the flow of gas, electricity, or water. The Autograph counts the pulses and converts periodic totals to engineering units with the scaling equations of Table A6.

Autograph Error. The Autograph is specified to have an error of ±0.03 percent of reading plus 0.012 percent of range. The netpac controller is the only board that introduces error into the sampled data (assuming secure connections throughout the system). It is calibrated every 25 seconds by the CPU.

Figure A7 shows the amount of error introduced by the Autograph. It compares transducer output of 100 to 500 mV (which is the 4 to 20 mA of the transducers measured across the 25 ohm input resistor of the Autograph) with mV error of the Autograph on the reading of the signal. This graph is valid for an input of 4 to 20 mA with the Autograph set to the 1 V range. Figure A7 can be used to derive error in the units of the measured process. Sample calculations which determine the maximum error in °F for the endpoints of a 0 to 250 °F RTD are shown below.

At 0 °F, the input voltage is 100 mV:

Reading Error	= 100 mV x 0.03 % = 0.03 mV
Range Error	= 1 V x 0.012 % = 0.12 mV
Total Max Error	= 0.15 mV (as shown in Figure A7.)
Actual Temp	= [(100 mV x 0.25) - 25] % span x 2.5 °F/% span = 0 °F (using scaling equation of Table A6)
Temp Error	= [((100 + 0.15) x 0.25) - 25] % span x 2.5 °F/% span = 0.094 °F
Δ F	= 0.094 - 0 = 0.094 °F

At 250 °F, the input voltage is 500 mV:

Reading Error = 500 mV x 0.03 % = 0.15 mV

Range Error = 1 V x 0.012 % = 0.12 mV

Total Max Error = 0.27 mV (as shown in Figure A7.)

Actual Temp = [(500 mV x 0.25) - 25] % span x 2.5 °F/% span = 250 °F (using scaling equation of Table A6)

Temp Error = [((500 +0.27) x 0.25) - 25] % span x 2.5 °F/% span = 250.17 °F

Δ F = 250.17 - 250 = 0.17 °F

The following equations can be used to derive Figure A7 for other ranges:

+ Error: Y = 0.0003X + range error

- Error: Y = -0.0003X + range error

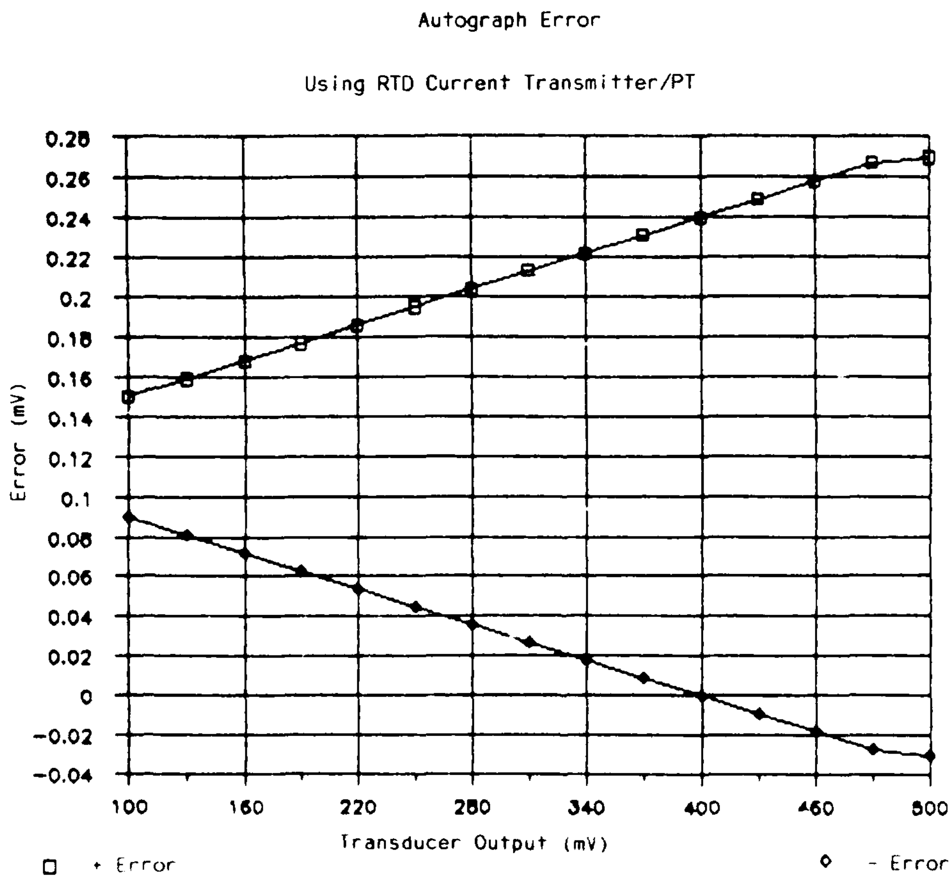

Figure A7. Datalogger error.

Barco Venturi and Viatran Pressure Transducer Flow Measurement System

Theory of Operation. Venturi/pressure transducer combinations are used to monitor water flow in hot water and chilled water loops in buildings (Figure A8). A venturi is basically a calibrated, tapered pipe. Water passing through the reduced area of the venturi throat increases in velocity, creating a pressure differential between the inlet and throat areas. This differential pressure across the venturi can be converted to a flow rate through the use of an energy balance (Bernoulli) equation. Two pressure taps on the venturi carry this differential pressure to a pressure transducer (PT) where it is converted to a 4 to 20 mA signal. Four strain gauges (connected in wheatstone bridge fashion with accompanying circuitry for linearization) sense the movement of the pressure transducer's diaphragm and produce a current proportional to the resistance of the bridge. The output signal from the bridge is amplified to provide a 4 to 20 mA ouput from the PT.

Three sizes of venturis are used to accommodate the varying pipe diameters in the water loops. Additionally, three ranges of pressure transducer are used, 0 to 5 psi, 0 to 10 psi, and 0 to 50 in. water column (wc) (0-1.8 psi). Table A7 gives the flow equations and flow ranges for the varying venturi/pressure transducer combinations. Table A8 gives the rated pump flow for each process measured and the venturi/PT combination assigned to monitor it. Manufacturer specifications for the PT are given in Table A9.

Figure A8. Venturi tube.

Table A7

Flow Equations and Flow Ranges for Venturi/Pressure Transducer Combinations

Aeroquip Venturi & Viatran Model #323 Pressure Transducers			
Venturi Model, Size, & Flow Equation	Flow Range (gpm) 0-5 psi PT (0-138.4")	Flow Range(gpm) 0-10 psi PT (0-276.8")	Flow Range(gpm) 0-50" wc PT
BR12427-24-31 1.5" dia. gpm=10("wc/15)**1/2	0-30.3754 gpm	0-42.9573 gpm	0-18.2574 gpm
BR27478-48-41 3" dia. gpm=100("wc/70)**1/2	0-140.6109 gpm	0-198.8539 gpm	0-84.5154 gpm
BR27465-64-41 4" dia. gpm=19("wc)**1/2	0-223.5227 gpm	0-316.1088 gpm	0-134.3502 gpm

Table A8

Locations, Measured Processes, Rated Pump Flow, and Model Numbers of Venturis

Building	Measured Process	Rated Flow	Venturi	PT
1361,1369 1669	Hot Water Supply 3" SCH 40	70 gpm	BR27478-48-41	0-5
1363,1666	Hot Water Supply 3" SCH 40	100 gpm	BR27478-48-41	0-10
1663,1667	Chill Water Supply 4" SCH 40	190 gpm	BR27465-64-41	0-5
811,812,813	Hot Water Pump #3 1.5" SCH 40	20 gpm	BR12427-24-31	0-5
	Hot Water Pump #2 3" SCH 40	70 gpm	BR27278-48-41	0-5
	Hot Water Pump #1 3" SCH 40	70 gpm	BR27478-48-41	0-5
	Chill Water Supply	190 gpm	BR27465-64-41	0-5

Table A9

PT Manufacturer Specification

Pressure Ranges	0-5 psid, 10 psid, 50 "wc
Supply Voltage	14-40V DC, 2-wire
Regulation	Less than ± .04%/V over supply voltage range.
Output Signal	4-20 mA, 2-wire
Load Impedance	1300 ohms max @ 40V DC
Accuracy	Better than ± .25% FSO including errors due to linearity and hysteresis.
Repeatability	Better than ± .1% FSO
Combined Zero &	Less than ± 2% FSO per 100 F
Span Temp. Eff. on accuracy Compensated	-30 to 180 F
Temp. Limits Operating	-50 to 200 F
Temp. Limits Range Cal.	± 1% FSO
Sig. Accuracy Ripple Less than	± .08% FSO
Proof Pres.	± 2000 PSID single ended with less than ± .25% FSO shift in calibration.
Burst Pres.	7500 PSI
Long Term	Better than .25% FSO over six months.
Stability Pos. Sens.	Mounts in any position.
Resp. Time	Less than 200 milliseconds to reach 90% FSO
Freq Response	Flat to 7 Hz
Shock Sens.	Less than 2.5 "wc / G in plane normal to the Diaphragm. Negligible in remaining 2 planes.
Weight	Less than 12 lbs (4.72 Kg)

Calibration Drift and Linearity. A two point calibration of the pressure transducers takes place by tweaking the output signal of 4 to 20 mA (100 to 500 mV at the Autograph) for the zero and span of the PT range. The zero point is achieved by isolating the PT from the water system, draining the water off the diaphragms, and exposing the diapragms to atmospheric pressure. The span point (full scale) is achieved by shorting two connections (pins) of a internal, manufacturer-supplied calibration circuit.

From field calibration data it was determined that the average daily drift for the Viatran pressure transducers is 0.0174 percent for the zero reading and 0.0218 percent for the span. This represents an average drift of 0.0737 mV and 0.1063 mV respectively at the Autograph input terminals. Table A10 is a summary of the error due to monthly drift for a 1.5 in. venturi and a 0 to 5 psid PT.

Although 0.65 percent drift/month may seem high it is not alarming when converted to gallons per minute (gpm): ±0.78 gpm/month. In fact, the difference in gpm error with drift at 0.01 percent (±0.685 gpm) and at 2 percent (±0.987) is small. This is due to the square root relationship between pressure and flow. For this project, the pressure transducers are calibrated once a month to insure accurate readings.

The pressure transducers are specified to have an accuracy better than ±0.25 percent of full scale output (FSO). Field tests of linearity were conducted on four PTs to determine field operating accuracies. A regulated air source supplied a varying pressure to the inlet port of the PT (0 to 10 in. Hg) while a U-tube manometer measured input pressures and an ammeter measured PT current output.

Figures A9 through A12 are graphs of the field data of milliamp output versus differential pressure input.

Table A11 gives the theoretical slope and least squares linearity for the PTs tested. Linearity is expressed as the maximum deviation of the experimental data from a specified straight line as percent of FSO. Theoretical slope linearity refers to a straight line between the theoretical endpoints. Least squares linearity refers to the straight line (through the experimental data points) for which the sum of the squares of the residuals are minimized.

Table A10

Observed Drift for a 1.5 In. Venturi with 0 to 5 psid Pressure Transducer

	Ave Monthly Drift	wc"	gpm trans only	gpm trans and venturi
zero error	+- 0.44225% +- 2.211 mV/month	0.612	+ 0.0671 - 0.0672	+ 0.7505 - 0.7506
span error	+- .65335% +- 3.188 mV/month	0.904	+ 0.0991 - 0.0994	+ 0.7825 - 0.7828

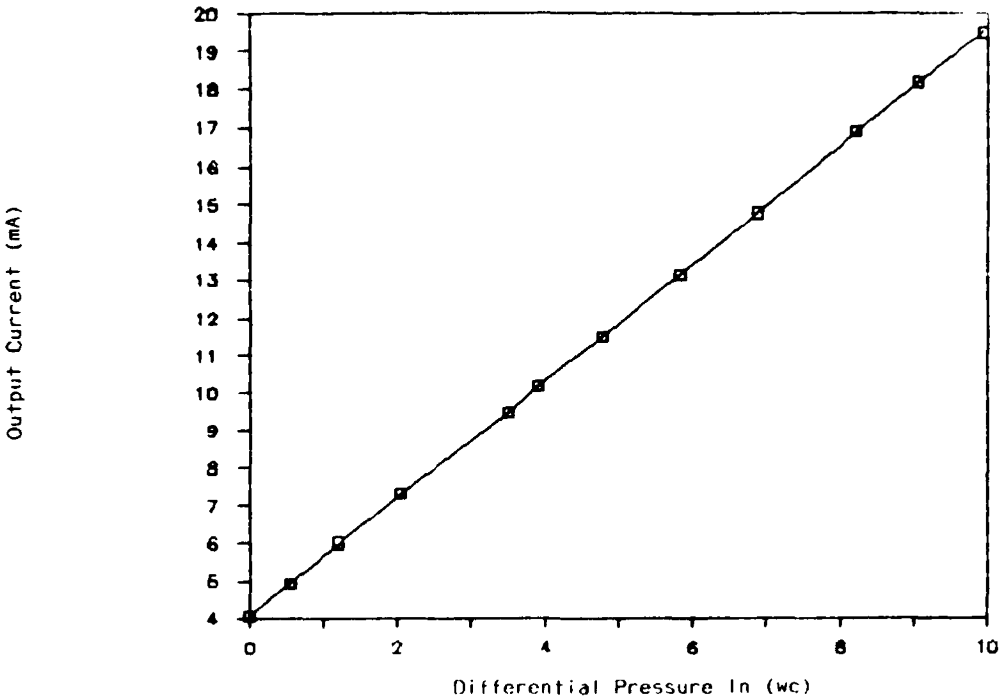

Figure A9. PT linearity for unit #1.

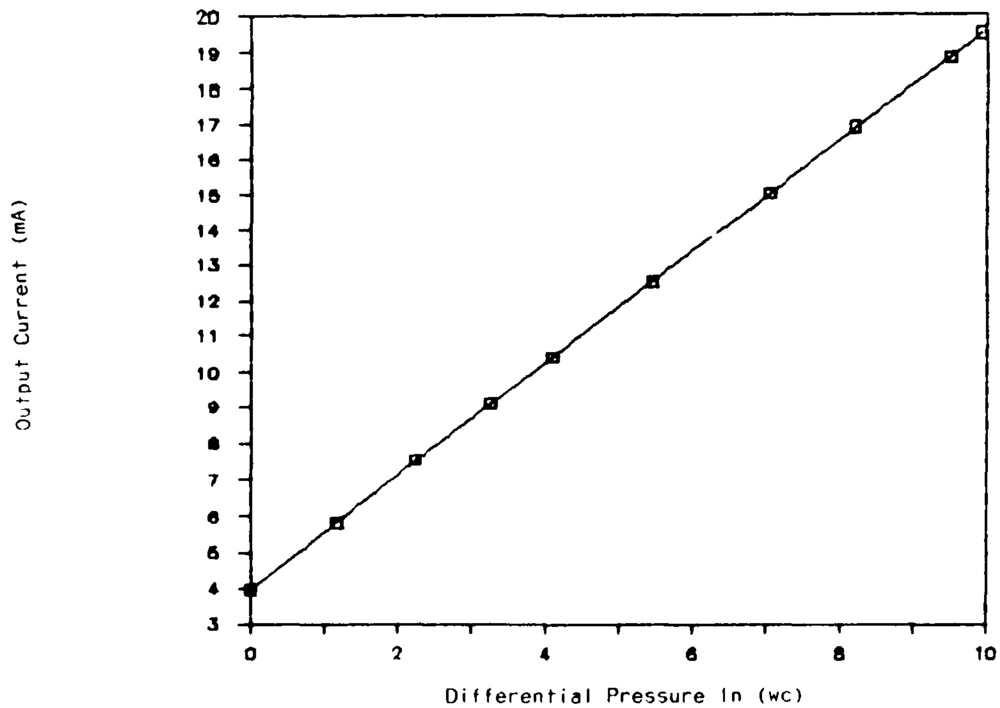

Figure A10. PT linearity for unit #2.

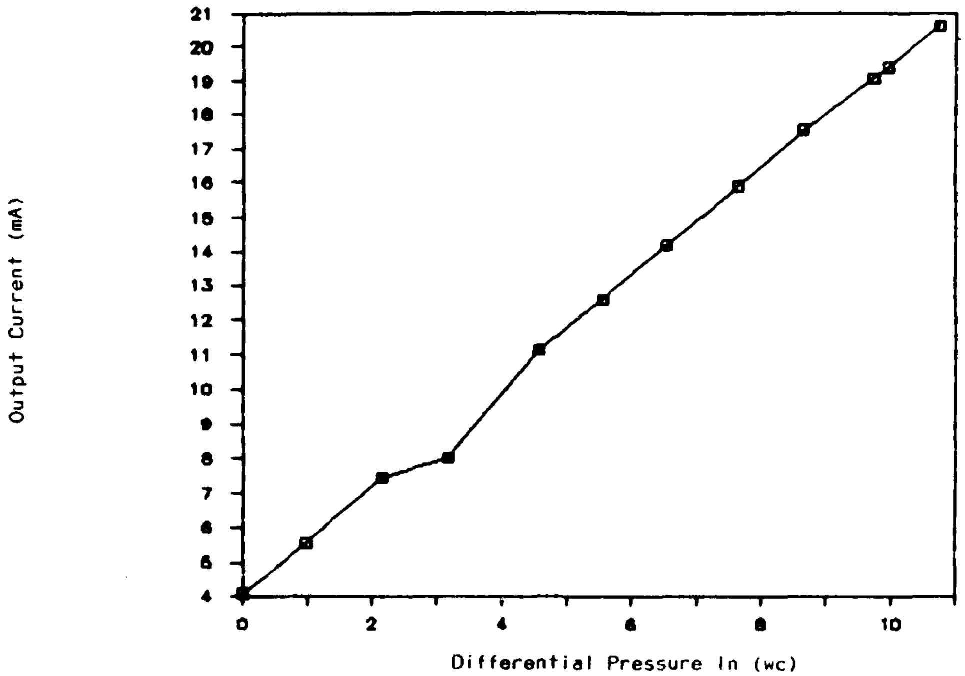

Figure A11. PT linearity for unit #3.

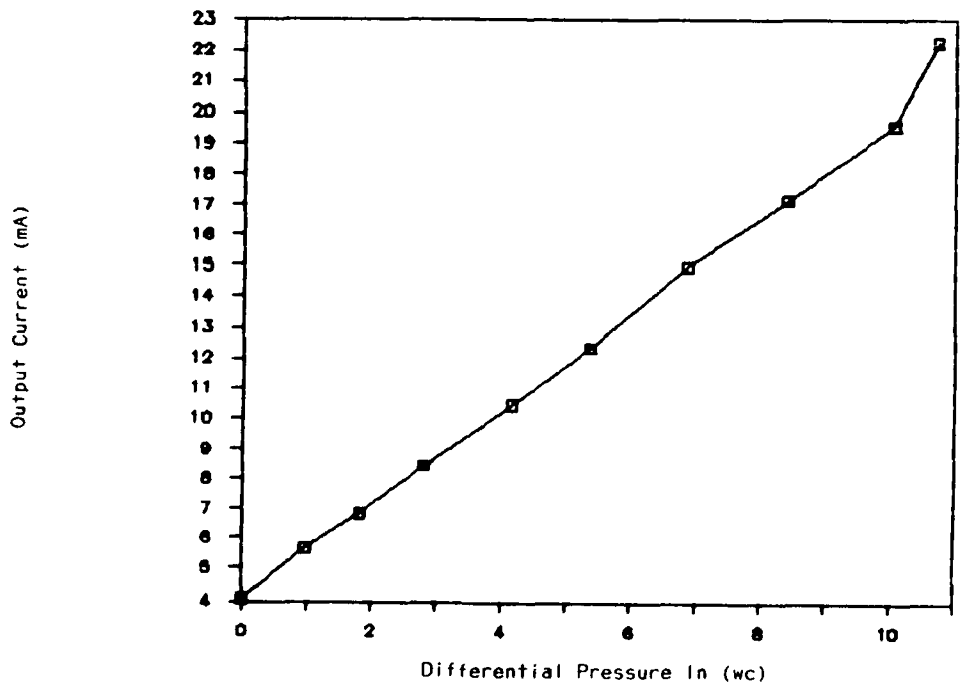

Figure A12. PT linearity for unit #4.

Table A11

Pressure Transducer Linearity (Calculated From Field Test Data)

	Theoretical Slope Linearity + - Max Deviation (%FSO)	Least Squares Linearity + - Max Deviation (%FSO)
Unit 1	0.388% -2.644%	0.318% -0.261%
Unit 2	-0.200% -2.412%	0.411% -0.742%
Unit 3	0.381% -3.387%	0.285% -0.998%
Unit 4	0.500% -1.813%	1.423% -0.460%

The results reveal that actual deviation from linearity of the PTs is greater than specified (0.25 percent). This may be due to wear experienced in operation. Additionally, the field test did not have the benefit of controlled lab conditions and thus may be subject to other random errors. Further testing is desirable to check the above results for accuracy and repeatability.

Insights on Operation. From lab experiments and field data, some interesting discoveries were made about the operation of the pressure transducers. Testing has been limited so results are all preliminary.

1. The pressure transducers experience more drift than the manufacturer specifies. This drift can be kept in check with frequent (monthly) calibrations.

2. The high end and low end output signals (span and zero) generally tend to drift in the same direction.

3. The power supplied to the pressure transducer greatly affects its performance. Each transducer has an internal regulator which, if not supplied with adequate voltage (about 12 V), will not be able to regulate the supply and act as a constant current source. This can be seen in Figures A13 and A14 which show the output signal versus supply voltage for a PT that was calibrated to 100 mV (zero) and 500 mV (span) at 15 V supply. The PT power supply voltage was varied while the current output was monitored by measuring the voltage across a 25 ohm resistor. The inability to maintain the appropriate output current for a constant input occurs below approximately 11 V for the low end (zero) of the PT range and below approximately 11.75 V for full scale output (span). Furthermore, higher supply voltages made the transducer less sensitive to supply voltage fluctuations.

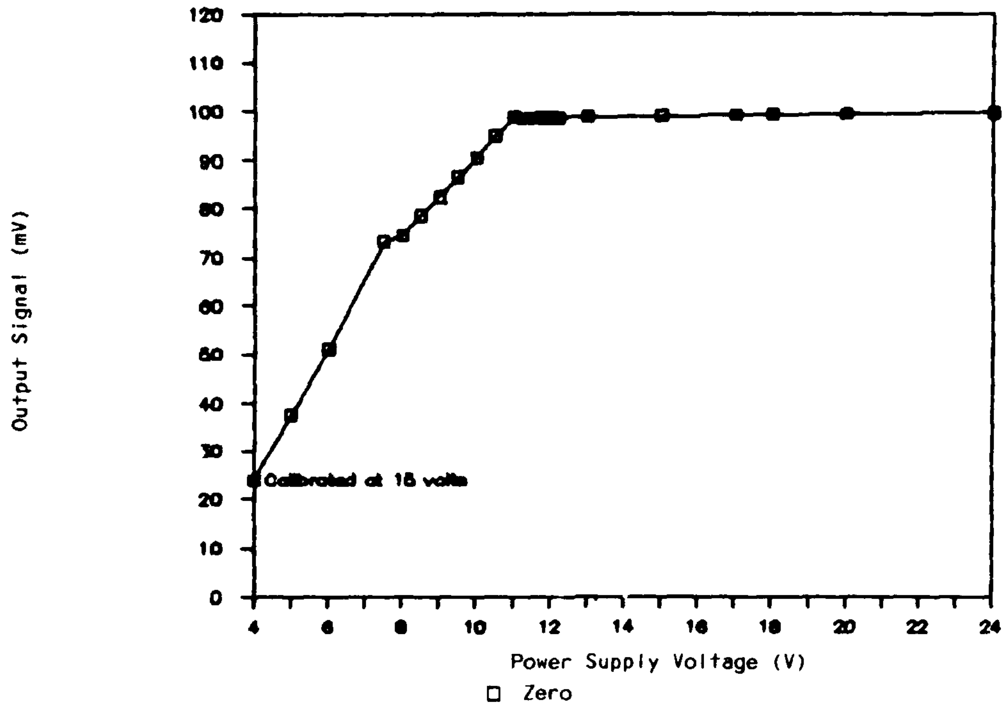

Figure A13. PT supply voltage change effect on zero reading.

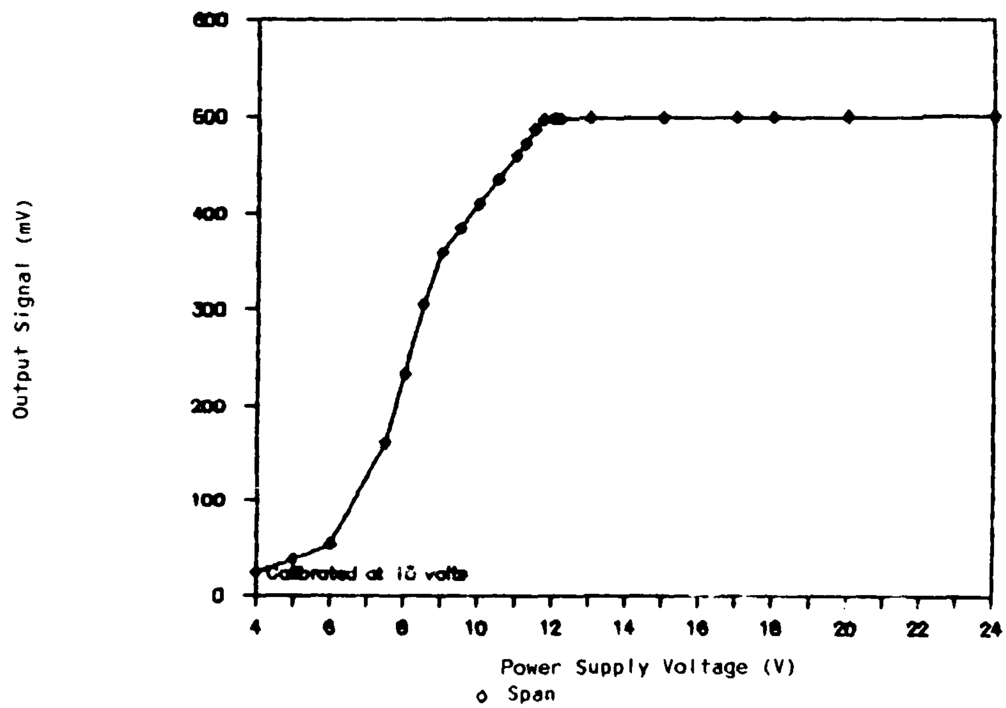

Figure A14. PT supply voltage change effect on span reading.

4. One lab test suggests that higher supply voltages made the pressure transducers less sensitive to external line resistance changes. Table A12 gives the change of the output signal versus external line resistance changes for two different supply voltages. Line resistance changes were made by adding resistors in series with the pressure transducer. The data show that the span output signal dropped by 5.4 V (from 498.4 V to 493 V) and 478.7 V (to 19.7 V) with a line resistance change of 25 ohms and 10,000 ohms, respectively. Corresponding signal changes with a 24 V supply were considerably less: 0.1 V (from 499.8 V to 499.7 V) and 456.47 V (to 43.33 V) respectively. Effects on the output signal at the low end of the instrument range (zero) were ambiguous. At a 25 ohm line resistance change there was no output change for both power supplies. At 10,000 ohms the output signal bottomed out for both supplies. Future tests should sample output signals at multiple line resistance changes to achieve higher resolution in the results.

This apparent sensitivity to power supply levels leads to the recomendation that a 24 V regulated power supply be employed in the future instead of the currently used 15 V power supply.

5. When calibrating a PT, one must allow the reading to stabilize, which takes about 10 seconds, between opening and shorting the full scale signal calibration pins. They have a settling time, probably due to transients in internal circuitry that provides the calibration signal. Time must be allowed for it to reach steady state.

6. The calibration meter should always be connected at the same point (the Autograph) to eliminate resistance changes due to line length variation that will affect voltage readings. Preferably, the same meter should be used to prevent differences in voltmeter calibration from being introduced in the calibration data. The same range setting should be used since the voltmeter rounds measured values to the current range accuracy.

7. Continuity of the leads greatly affect the reading. Alligator clips in particular, yield erratic readings in lab tests. It is recommended that only hooked clips on micro leads or spade lugs be used.

8. The main failure mode of the PTs seems to be attributed to the internal electronic calibration circuitry. Usally the PTs are replaced because they can not be calibrated within limits to the proper zero and span range specifications. Another PT failure which has occurred but is less common happens when a PT calibrates properly but outputs an erroneous signal when in operation, due to strain gauge problems.

Table A12

Effect of Load and Supply Variations on Pressure Transducer Calibration Settings

	Span			Zero		
Supply (volts)	Init. (mV)	+ 25 ohms (mV)	+ 10k (mV)	Init. (mV)	+25 ohms (mV)	+ 10k (mV)
12.2	498.4	493	19.7	98.65	98.65	19.7
24.0	499.8	499.7	43.33	99.62	99.62	43.33

Error Analysis. Table A13 summarizes the error introduced by the venturi and PT. The calculations were done for a typical, root sum of squares (RSS), error. Table A14 shows the errors arising from various combinations of venturi and PT at the maximum flow.

Table A13

Venturi/Pressure Transducer Error Summary

PRESSURE TRANSDUCER:		
Instrument accuracy± 0.25% FSO including linearity and hysteresis		
Repeatability		± 0.10% FSO
Combined zero and span temperature effects on accuracy (± 2.0% FSO per 100 °F)		± 2.0% FSO
Range calibration signal accuracy		± 1.0% FSO
Ripple		± 0.08% FSO
Calibration (1 mV error)		± 0.6% FSO
	RSS ERROR	± 2.33% FSO
Long-term stability		± 0.25% FSO over six months
Average daily drift (from field data)		± 0.0174% FSO for the zero
		± 0.0218% FSO for the span
VENTURI:		
Accuracy of venturi		± 2.0% of reading
GPM correction due to temperature		± 0.25% of reading
	RSS ERROR VENTURI	± 2.02% of reading
	RSS Error PT and Venturi	± 3.08%

Table A14

GPM Error on Venturi/Pressure Transducer Combinations at Maximum Flow

VENTURI	PRESSURE TRANSDUCER 0-5 psi %	gpm	0-10 psi %	gpm	0-50 wc" %	gpm
1.5"	3.08	+0.965 -0.960	3.08	+1.11 -1.11	3.08	+0.825 -0.820
3"	3.08	+2.24 -2.26	3.08	+2.92 -2.94	3.08	+1.59 -1.60
4"	3.08	+3.20 -3.23	3.08	+4.28 -4.32	3.08	+2.17 -2.18

Hy-cal Current Transmitter With 100-Ohm Platinum RTD

This section explains the theory of operation of the three-wire RTDs and associated current transmitters used for measuring air and water temperature in this project. Detailed attention is given to lead length compensation for remote temperature sensing. Manufacturer specifications are given in Tables A15 and A16.

Temperature Sensing. Hy-cal current transmitters (CTs) are used in conjunction with 100 ohm platinum RTDs to measure temperature (Figure A15). The resistance of an RTD changes approximately linearly with temperature. A 100 ohm platinum RTD has a nominal resistance of 100 ohms at 32 °F (0 °C), which changes proprortionally with a constant known as the temperature coeficient. The RTDs used with this project have a temperature coeficient of 0.214 Ω/°F. The current transmitter reads the resistance at its input (the RTD) and outputs a current which is linearly proportional to this resistance. For example a 32 to 122 °F CT is designed to operate linearly with an input resistance between 100 and 119.25 ohms. It will output 4 mA at 100 ohms (32 °F) and 20 mA at 119.25 ohms (122 °F). The current transmitter works on the bridge principle. It uses a three-wire RTD to complete the circuit of a wheatstone bridge to detect changes in the RTD's resistance. Changes in resistance in the bridge result in voltage changes out of the bridge which are converted to a current output. The Autograph receives 4 to 20 mA signals from the CT and converts them to °F.

Three-Wire RTD. When using an RTD to measure temperature, there are four possible sources of error: (1) lead wire error, (2) self-heating of the bridge components, (3) resistance change of lead wire due to ambient temperature, and (4) linearity of the RTD itself. Self-heating error compensation is accounted for by the manufacturer and will be briefly discussed. To minimize linearity error, the RTD is matched to the CT by the manufacturer. The supply and return temperature sensing RTDs are also matched so that the linearity error in one is compensated by the other to achieve a ΔT with minimum error.

Table A15

CT Manufacturer Specification

Indoor Temperature Transmitter

Model	CT-822-A-A-L-(32-+122F)
Resistance	100 Ohm
Accuracy	.1% of span
Range	32-122F
Output	4-20 mA
Description	Hinged weather proof box

Outdoor Temperature Transmitter

Model	CT-822-A-A-L-(-50-+150F)
Resistance	100 Ohm
Accuracy	.1% of span
Range	32-122F
Output	4-20 mA
Description	Hinged weather proof box

Water Temperature Transmitter

Model	CT-822-A-A-L-(0-+250F)
Resistance	100 Ohm
Accuracy	.1% of span
Range	32-122F
Output	4-20 mA
Description	Hinged weather proof box

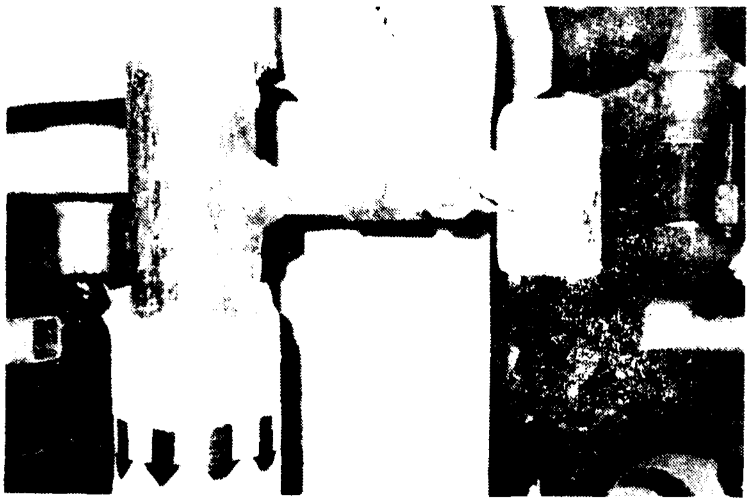

Figure A15. Pipe containing resistance temperature detector.

Table A16

RTD Manufacturer Specification

Indoor Sensor

Model	RTS-5737-K-T-3-18-X1
Range	-58 F to 150 F
Resistance	100 Ohm
Type	Thin film, .00385 ohm/ohm/C platinum
Self Heating	15 mW / C
Accuracy	.1% of temp.
lead Wire	3-wire,teflon insul,nickel coated copper
Description	Wall mount air temp. sensor

Outdoor Sensor

Model	RTS-5737-W-T-3-18-X1
Range	-58 F to 176 F
Resistance	100 Ohm
Type	Thin film, .00385 ohm/ohm/C platinum
Self Heating	15 mW / C
Accuracy	.1% of temp.
lead Wire	3-wire,teflon insul,nickel coated copper
Description	Outdoor air temp. sensor

Imersion Sensor

Model	RTS-36-T-100-C-7-3-8-X1
Range	-320 F to 500 F
Resistance	100 Ohm
Type	Thin film, .00385 ohm/ohm/C platinum
Self Heating	15 mW / C
Accuracy	.1% of temp.
lead Wire	3-wire,teflon insul,nickel coated copper
Description	Double thread fittings at end

The RTD is sensitive to self-heating which causes its value to change. The heat generated by any resistive element will be proportional to the amount of power that it draws as given by $P = I^2 \times R$, where P = power, I = current, and R = resistance. This relationship shows that the heat generated by a resistive element will be proportional to the square of the current passing through it. Generally the technique used to reduce this current is to make the resistors at the top of the bridge 10 times greater than the lower resistors, which include the RTD.

The resistance of an RTD varies in accordance with its temperature coeficient; however each RTD will have a unique resistance versus temperature characteristic (a different linearity curve). They are tested and labeled by the manufacturer according to the range of best linearity. For instance, if after testing it is found the range of temperatures where resistance varies most linearly is 20 to 150 °F, then the manufacturer labels it as a 32 to 122 °F RTD to be used with a CT of this type. When an RTD and a CT of the same type are used, the linearity error is limited to manufacturer specifications.

To understand how an RTD is used in a bridge leg, consider the simple series circuit of Figure A16. A resistor in series with an RTD is powered by a constant voltage source V. The voltage at point b will depend on the ratio of the resistance of the RTD to the total resistance of the RTD and resistor (a standard voltage divider). This voltage V_{bc} will therefore be proportional to the temperature sensed by the RTD, since the RTD's resistance changes with temperature.

Next consider the circuit of Figure A17. Here another series resistance combination is placed in parallel with the first. This is known as a wheatstone bridge. The voltage at nodes b and d will depend on the ratio of the resistors (R_{ab}/R_{bc} and R_{ad}/R_{dc}) in the two parallel resistance combinations. The voltage out of the bridge is $V_{dc} - V_{bc}$ and thus depends on the four resistor values in the bridge. Since one of these resistors is an RTD and the other three resistors have a fixed value, the voltage out of the bridge will be proportional to the resistance change of the RTD.

To understand the lead wire compensation of an RTD return to Figure A16, and suppose that the RTD was immersed in water and placed 25 ft from the power source. The second resistor, R_{bc}, would consist of the platinum RTD in series with 50 ft of copper wire (which also makes an excellent RTD itself). In this situation, the resistance change seen by the circuit would indicate the temperature of the water and also the temperature gradient of the ambient air along the 25 ft distance that separates circuit and sensor. However, without changing the circuit we can minimize lead wire error if we take our voltmeter at point b and slide it 25 ft along this node from the circuit to the RTD. Since $R_{bwire} = R_{cwire}$ we have added the same amount of resistance to the numerator and denominator, minimizing the lead wire effect as far as the ratio (R_{ab}/R_{bc}) is concerned. That is, the ratio R_{ab}/R_{rtd} is closer to and approximately equal to the ratio $(R_{ab} + R_{bwire})/(R_{rtd} + R_{cwire})$. The lead wire error will be negligible as long as the $R_{rtd} >> R_{wire}$. The point here is that the correct reading can be obtained simply by shifting the point where the reading is taken.

The same idea applies as well to the wheatstone bridge. Figure A18 shows a three-wire wheatstone bridge with an RTD that is 25 ft away connected to complete the circuit. The third lead of the RTD has the effect of shifting the node of the bridge so that an equal amount of resistance is added above and below the node. Thus, lead wire error is canceled by adding an equal amount of resistance to opposing legs. This has the added benefit that any resistance change due to temperature of both lead wires will be the same since they extend over the same distance.

Error Analysis. The RTD and current transmitters are matched by the manufacturer for best performance. They are specified to have an interchangeability error of 0.1 percent at 0 °C. Table A17 lists the calculated system error when using the RTD/CT combination.

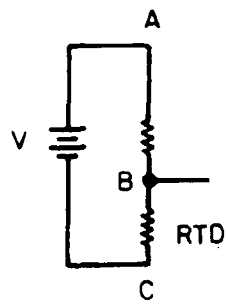

Figure A16. A series circuit.

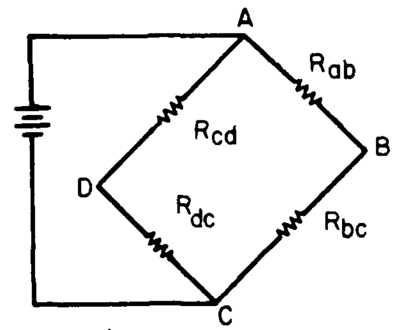

Figure A17. A wheatstone bridge.

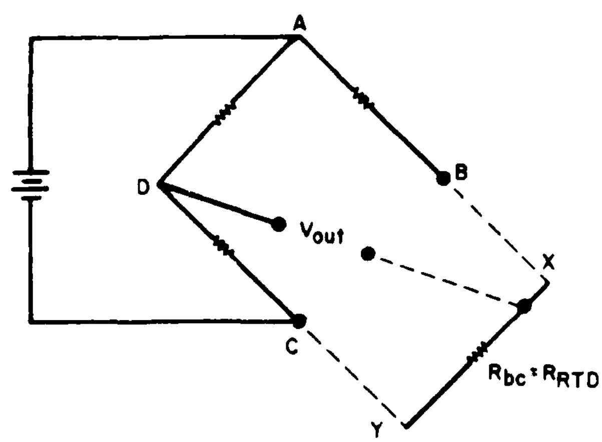

Figure A18. An RTD in a wheatstone bridge.

Table A17

Current Transmitter and RTD Error Summary

-50 to 150 °F	Fahrenheit	Celsius
linearity	± .2	± .11
Bemex Box	± .138	± .078
Temp Stability	± .002 F/F	± .033 C/C
Autograph Resistor	± .12	± .07
Calibration Error	± .2	± .11
RTD	± .7	± .3
Drift/6 months	± .5	± .28
32 to 122 °F	**Fahrenheit**	**Celsius**
linearity	± .09	± .05
Bemex Box	± .138	± .078
Temp Stability	± .002 F/F	± .033 C/C
Autograph Resistor	± .03	± .06
Calibration Error	± .09	± .05
RTD	± .7	± .3
Drift/6 months	± .5	± .28
0 to 250 °F	**Fahrenheit**	**Celsius**
linearity	± .25	± .14
Bemex Box	± .138	± .078
Temp Stability	± .002 F/F	± .033 C/C
Autograph Resistor	± .15	± .08
Calibration Error	± .25	± .14
RTD	± .7	± .3
Drift/6 months	± .5	± .28

RTD & C.T. Model Type

	RTD	C.T.
Indoor Sensor	RTS-5737-K-T-3-18-X1	CT-822-A-A-L-(32-+122F)
Outdoor Sensor	RTS-5737-W-T-3-18-X1	CT-822-A-A-L-(-50-+150F)
Imersion	RTS-36-T-100-C-6-3-8-X1	CT-822-A-A-L-(0-+250F)

Badger Flowmeter

This project uses Badger positive displacement flow meters to measure cold water feed for domestic hot water and condensate flow (Figure A19). Flow is logged from weekly readings of the meter's six-digit, nonresetable, totalizing register and also from contact closures, which are sent to the Autograph where they are totaled and recorded.

The Badger flow meters are Model SC-ER-C. These meters are rated to carry liquids up to 120 °F. Accuracy over the full flow range of the meter is within ± 2 percent. The meter consists of a bronze housing that contains a measuring chamber and a nutating disk. Liquid passes through the inlet into the measuring chamber, and causes the disk to nutate and then exits through the outlet. Each nutation of the disk is proportional to a specific volume of liquid. The nutating motion of the disk drives a magnet assembly that magnetically links with a follower magnet on accessories such as a register or contact-closure-pulse transmitter.

In this field demonstration, it was found that the meters operate best in the face up or the vertical position. One meter that was installed face down due to space limitations failed; water filled the register/pulse initiator unit.

Rockwell Gas Meter

Rockwell Model 1000 and 5000 gas meters are used to measure total gas consumption. Gas flow is logged from weekly readings of the meter's six-digit, nonresetable, totalizing register, and also from contact closures which are sent to the Autograph where they are totaled and recorded. The meters are rated to have a ± 1 percent accuracy at 0.6 specific gravity gas at 60 °F within the given pressure and flow limits of the meter. Additional specifications for these meters are contained in Table A18.

The Rockwell meters are positive displacement flow meters, where a known volume of gas is alternately trapped and released in chambers. This process moves diaphragms which are connected to mechanical linkages which count the number of cycles.

General Electric Watthour Meter

GE Model VW-65-S watthour meters are used to measure electric consumption in all the buildings. These are polyphase, multistator, totalizing meters with registers and pulse initiators. Meter readings are obtained from the register weekly by a field technician and from contact closure pulses that are sent to the Autograph and totaled.

The watthour meter is an electromechanical device that measures electrical energy consumption. The meter operates similar in principle to an electric motor. Potential and Current coils (stator in a motor) measure voltage and current respectively and generate an electromagnetic field that is indicative of power (power = voltage * current). This field produces a torque on the meters disk (rotor in a motor) that causes it to spin. Permanent magnets are used to create a retarding force proportional to disk speed so that no matter how fast the disk is spinning, each revolution will represent the same amount of energy (kWh). This is called the meters constant Kh. The disk rotation is geared to the register and a pulse initiator.

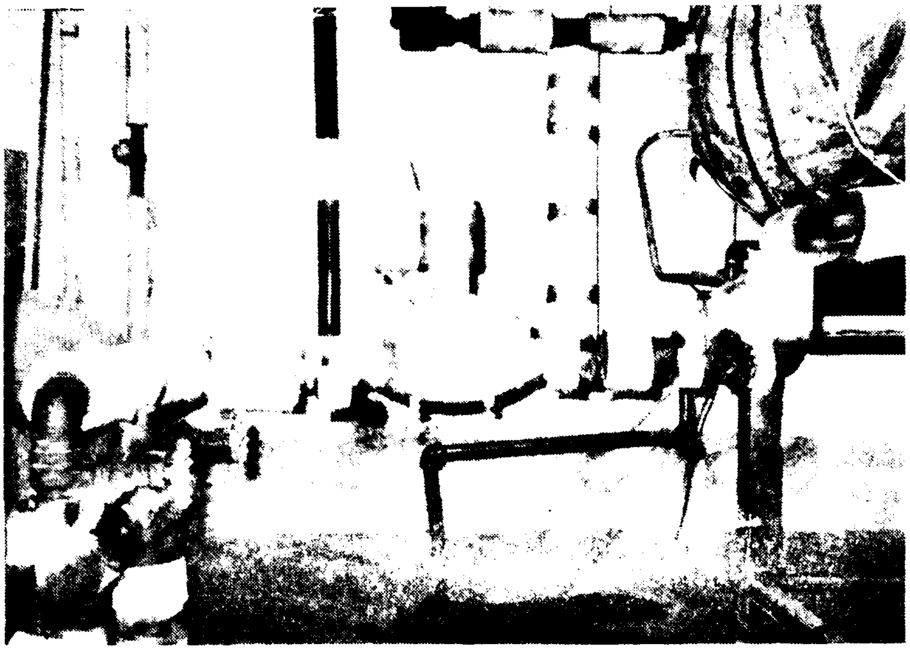

Figure A19. Positive displacement flow meter.

Table A18

Rockwell Model 1000 and 5000 Gas Meter Specifications

	Model	
	1000	5000
Max Working Pressure	25 psig	100 psig
Capacity at 0.5 w.c. differential of 0.6 gravity gas	1000 cu ft/hr	5000 cu ft/hr
Cuft/rev of Output Shaft	10 cu ft/hr	10 cu ft/hr
Rev / cuft	1.6	0.5
Weight	80 lbs	198 lbs

System Troubleshooting

System troubleshooting is accomplished by checking progressively smaller component subsystems, excluding adequately functioning subsystems from further investigation, then zeroing in on and eliminating the source of the problem. The process is challenging but becomes streamlined with experience.

Most of the anomalies associated with the instrumentation are assumed to be due to high environmental temperature. The majority of the technical problems occur in the datalogger and its modem. In the Autograph, most failures are due to malfunctioning netpacs or CPU boards.

The troubleshooting sequence is best described by an example. For instance, consider a situation where a room temperature is registering 90 $^{\circ}$F at the Autograph. This temperature is possible but highly unlikely.

1. A troubleshooter would start by measuring the actual room temperature with a hand-held thermometer. This would identify an actual overheating problem in the building and potentially verify that the DAS is operating adequately. Should the thermometer and Autograph reading not coincide, the following actions would be taken.

2. The Autograph scanning would be stopped, then started. This would reset the Autograph's registers and clear any momentary glitches which may have occurred.

3. The voltage test block on the Autograph would be verified for the apropriate voltage levels. This would identify several potential power supply problems in the Autograph.

4. The Autograph programming would be checked. A check of the programming of the nominal channel assigned to this parameter would verify that the appropriate physical input was being addressed, that the actual signal in question was being converted with the correct scaling equations, and that any averaging or totaling was programmed as intended.

5. Following these fairly nonintrusive procedures, the power to the Autograph would be cycled off then on again. The procedure tends to have a tremedous healing effect on malfunctioning equipment.

6. Next, the wiring for this channel would be switched with a properly functioning channel to make sure the problem was indeed in the instrumentation and not the Autograph or its accessories.

7. Next, the RTD would be checked. A measure of the resistance of the RTD (leads Ra-bc) would verify that the RTD had the correct resistance for the temperature reading.

8. Next the current transmitter (CT) would be checked. A measure of the current through the signal loop could be checked against the CT's equation (i.e., current 16/250 x temp + 4). If it failed, a subsequent investigation would include checking the CT's power supply for necessary output voltage, checking the CT calibration, checking for discontinuities in the wiring, and checking that the Autograph's input resistor is not burned out.

9. Assuming the CT checked out, the Autograph's resistor would then be checked. A measure of the voltage across the resistor should equal 25 times the current of the previous step.

10. If the problem's source has still not been identified, the Autograph would be checked on a component level. Autograph troubleshooting is accomplished by selectively removing circuit boards or assemblies and replacing them.

The failure of circuit boards is verified by the installation of a new circuit board which clears the problem, followed by reinsertion of the original board which restablishes the problem. Also before removing the CPU or power supply assembly, an internal diagnostic check should be performed after downloading data files. This diagnostic performs a memory clear, checks the Autograph's RAM, programmable read only memories (PROMs), and checks the keyboard. The diagnostic is initiated by switching the Autograph off, placing the toggle switch on the CPU in the clr (inboard) position, repowering the Autograph, placing the toggle switch in the original position, and pressing the scan key twice. The operator should watch the front panel display for any error messages.

Table A19 lists some of the more common problems. Table A20 is a compilation of the data values recorded at the Autograph for various types of signal errors. This table can be used as a troubleshooting aid for flagging errors from data files.

Table A19

Common Instrumentation Problems and Solutions

PROBLEM	POSSIBLE SOLUTIONS
Temperature out of range	Stop and start scan, check power supply voltage at test connector on the back of the Autograph, check the room temperature with a hand held thermometer, check the programming, cycle Autograph power, swap problem channel with a known good channel to see if bad channel now reads properly, measure the resistance of theRTD, check c.t. calibration, check current through the signal loop, measure the resistance of the Autograph resistor and inspect it for cracks, check instrumentation wiring at input card, check instrumentation wiring at panel box, clean connections and reseat netpac board, swap netpac, perform diagnostics, clean connections and reseat cpu, swap cpu.
Flow out of range	Stop and start scan, check power supply voltage at test connector on the back of the Autograph, check the programming, cycle Autograph's power, swap problem channel with a known good channel to see if bad channel now reads properly, make sure p.t. calibration leads are not shorted, check p.t. calibration, check current through the signal loop, measure the resistance of the Autograph resistor and inspect it for cracks, check instrumentation wiring at input card, check instrumentation wiring at panel box, clean connections and reseat netpac board, swap netpac, perform diagnostics, clean connections and reseat cpu, swap cpu.
One channel has a constant value	Stop and start scan, check power supply voltage at test connector on the back of the Autograph, check the program ming, cycle Autograph's power, swap problem channel with a known good channel to see if bad channel now reads properly to rule out Autograph as the source of error, check wiring for either open or short circuit, check current through the signal loop, check instrumentation wiring at input card, check instrumentation wiring at panel box, clean connections and reseat netpac board, swap netpac, perform diagnostics, clean connections and reseat cpu, swap cpu.
All neg. values	Stop and start scan, check power supply voltage at test connector on the back of the Autograph, check the program ming, cycle Autograph power, press input card in firmly, check power to c.t.'s and p.t.'s, check instrumentation wiring at input card, check instrumentation wiring at panel box, clean connections and reseat netpac board, swap netpac, perform diagnostics, clean connections and reseat cpu, swap cpu.

Table A19 (Cont'd)

"Comm Error"	Stop and start scan, check power supply voltage displayed at test connector on the back of the Autograph, check the programming, cycle Autograph's power, press netpac in firmly, clean connections and reseat netpac board, swap netpac, perform diagnostics, clean connections and reseat cpu, swap cpu.
"Overrange Error"	Stop and start scan, check power supply voltage displayed at test connector on the back of the Autograph, check the programming, cycle Autograph power, check current through the signal loop, measure the resistance of the Autograph resistor and inspect it for cracks, check instrumentation wiring at input card, check instrumentation wiring at panel box, clean connections and reseat netpac board, swap netpac, perform diagnostics, clean connections and reseat cpu, swap cpu.
Autograph locked not scanning, does not acknowledge instructions locally or re-motely. Front panel keyboard does not respond to touch.	Stop and start scan, check power supply voltage at test con nector on the back of the Autograph, send control-Q, Cycle power, disconnect RS232 sources cables and power up, swap modems, clean connections and reseat netpac, perform diagnostics, clean connections and reseat boards in the following order: input cards, netpac, printer board, pulse board, cpu, swap boards in the aforementioned order, replace power supply.
Printer not working	Stop and start scan, turn the printer offline and press press self test button, place printer back online and watch the status lights on the Autograph for status 1. Status 2 indi-cates paper supply is low, status 4 indicates top of form not alligned, status 7 indicates communication error, clean con-nections and reseat printer controller board, check power supply voltage at test connector on the back of the Auto-graph, check belts, check programming, cycle Autograph power a few times, swap printer board, perform diagnostics, clean connections and reseat cpu, swap cpu.
Display blank	Make sure Autograph is switched on, check for power at the Autograph power strip, stop and start scan, check power supply voltage at test connector on the back of the Auto-graph, cycle Autograph power, clean connections and reseat battery charger board, swap battery charger board, clean connections and reseat display board (behind front panel), swap display board, perform diagnostics, clean connections and reseat cpu, swap cpu.
Every pixel lit on display	Stop and start scan, check power supply voltage at test con-nector on the back of the Autograph, check programming, cycle Autograph power, clean connections and reseat display board (behind front panel), swap display board, perform diagnostics, clean connections and reseat cpu, swap cpu.

Table A19 (Cont'd)

Huge numbers on all pulsed chans.	Stop and start scan, check power supply voltage at test connector on the back of the Autograph, check the programming, cycle Autograph's power, clean connections and reseat pulse board, swap pulse board, perform diagnostics, clean connections and reseat cpu, swap cpu.
Autograph switch off	This switch is really a circuit breaker. If it is off, then then there was a power surge or someone turned it off. Turn Autograph on and check power supply voltages at test connector on the back of the Autograph and verify that they are correct. If Autograph will not power up then replace the power supply assembly.
Program and/or data loss	Check for power at power strip and check the power strip circuit breaker, check power supply voltage at test connector on the back of the Autograph, make sure switch on RAM card is in on position, check fuse on battery charger board, check battery voltage and verify that it is 6 volts; if not install a new battery charger board and see if battery charges, replace battery, perform diagnostics, clean connections and reseat RAM card, swap RAM card, clean connections and reseat cpu, swap cpu.
Incorrect Date	Check power supply voltage at test connector on the back of the Autograph, check fuse on battery charger board, check battery voltage and verify that it is 6 volts; if not install a new battery charger board and see if battery charges, replace battery, perform diagnostics, clean connections and reseat cpu, swap cpu.
Modem power light not lit	Check for power at power strip and check the power strip circuit breaker, exchange the modem power supply with another to see if problem clears up, swap modem.
Modem answers, but no response	Hang up and recall, press reset switch, check communications protocol settings, swap modem. Autograph may be locked up (see those procedures).
Modem rings, but won't answer	Check that modem power light is on (see no power procedure power procedure if light is not on), press reset switch, check modem cabling for continuity, install a new modem to see if the problem clears up then replace it to see if the problem returns, if DTR light is not lit then perform diagnostics, clean connections and reseat cpu, swap cpu.
Line always busy but wont answer	Check that modem power light is on (see no power procedure power procedure if light is not on), press reset switch, swap modem.
Carrier always on	Hang up and recall, press reset switch, install a new modem to see if the problem clears up then replace it to see if the problem returns.

Table A20
Values Received for Various Types of Sensor Failures

Parameter	Value	Indication
Outside Temperature (-50 F - 150 °F)	< -125 F	reversed leads
	-100 F	open circuit
	< -16 F	minimum from NOAA 1985 summary
	> 97 F	maximum from NOAA 1985 summary
Inside Temperature (32 F - 122 °F)	<-57.6 F	reversed leads
	9.5 F	open circuit
	< 60 F	practical inside minimum
	> 80 F	practical inside maximum
Water Temperature (0 F - 250 °F)	< -75 F	reversed leads
	-62.5 F	open circuit
1.5 " Venturi & 0-5 psid Pressure Transducer	< -25 gpm	reversed leads
	-15 gpm	open circuit
	> 30.2 gpm	pins 3 & 4 shorted on PT
3 " Venturi & 0-5 psid Pressure Transducer	< -100 gpm	reversed
	-70 gpm	open circuit
	> 150 gpm	pins 3 & 4 shorted on PT
4" Venturi & 0-5 psid Pressure Transducer	< -150 gpm	reversed leads
	-112 gpm	open circuit
	> 220 gpm	pins 3 & 4 shorted on PT
3" Venturi & 0-10 psid PT	< -125 gpm	reversed leads
	-100 gpm	open circuit
	> 190 gpm	pins 3 & 4 shorted on PT

APPENDIX B:

DATA ACQUISITION SOFTWARE

Overview

The Remote Data Acquisition Support System (RDASS) is a family of customized computer programs which facilitate the large scale data acquisition effort of this project. Major utilities enable remote programming of data acquisition equipment, remote retrieval of site data, and remote monitoring of field instrumentation for possible equipment malfunction. The system is specifically for use with the IBM-AT, Autograph, and Microcom modems. It is written in a combination of MS-DOS operating system commands, Symphony macros and compiled BASIC programs running on the IBM-AT. RDASS functions can be executed interactively or in an automated batch fashion.

Programming the Data Acquisition System (DAS)

RDASS provides full communications support between microcomputer and datalogger, allowing downloading of individual DAS commands or whole DAS program files and the verification of programming at the Autograph. Since the Autograph will not accept commented code, RDASS will process the commented DAS program textfiles generated with the PC's editor and strip off all comments and extra spaces to produce an Autograph-ready file.

Automated Acquisition

Automatic data acquisition is the normal method for retrieving data. The IBM-AT is mechanically clocked to power up at night, telephone the dataloggers in 11 buildings at Fort Carson, retrieve data files, analyze the data, generate reports indicating the condition of the instrumentation, and then turn off. A hard copy synopsis of the evening's activities is waiting for inspection in the morning (Figure B1).

This automated mode is a substantial time-saver over the manual mode of data retrieval that was initially used, which often required 3 hours of the system operator's time.

Determining the Work Schedule

On powering up, RDASS is commanded by an autoexec file which begins executing as soon as the computer is turned on. Initial duties include determining the current date and time to identify the required work sequence for the day. On most days a small sampling of minute data from each building will occur. On two selected days during the week, larger hour data files will be retrieved. Additionally, RDASS will determine if the program has already been executed for the day to avoid any possible file overwrites in the event of timer or electrical service malfunction. Once the work schedule is determined RDASS steps through a telephone list and calls each of the 11 building, performs the scheduled tasks, then continues to the next building. RDASS keeps hard copy notes of its progress throughout its execution (Figure B2).

ECRSD building states report for : 27-Jun-87

Building 635	Building 813	Building 1369	Building 1667
10 attempts made and failed. Not talking	HD27JN87.W0 HD27JN87.W1 SD27JN87.W0 Time (01:07) Date (27-Jun-87)	HR27JN87.W0 SR27JN87.W0 Time (01:17) Date (27-Jun-87)	HU27JN87.W0 SU27JN87.W0 Time (01:26) C3 2nd floor temp (94) Date (27-Jun-87)

Building 811	Building 1361	Building 1663	Building 1669
HM27JN87.W0 HM27JN87.W1 SM27JN87.W0 Time (01:02) C23 Chilled water flow (-33) Date (27-Jun-87)	HP27JN87.W0 SP27JN87.W0 Time (01:10) Date (27-Jun-87)	HQ27JN87.W0 SQ27JN87.W0 Time (01:19) Date (27-Jun-87)	HV27JN87.W0 SV27JN87.W0 Time (01:28) Date (27-Jun-87)

Building 812	Building 1363	Building 1666	Notes
HN27JN87.W0 HN27JN87.W1 SN27JN87.W0 Time (01:05) C14 Zone 1 HW return temp (-36) C15 Zone 1 HW supply temp (-36) Date (27-Jun-87)	HO27JN87.W0 SO27JN87.W0 Time (01:14) C17 Electric use (1573) Date (27-Jun-87)	HT27JN87.W0 ST27JN87.W0 Time (01:22) Date (27-Jun-87)	

03:28 PM 27-Jun-87

Figure B1. Sample daily status report from single minute data.

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=================================================================================

NOW AT BLDG 811              FT. CARSON TIME IS 09:45:55
History files reset at building 811
F03/2

NOV16,87                                              CERL ECRSD B811 R6.3 MIN


09:45:58  C001        811.63 BLDG    C002          31.3 DEGF    C003          9.5 DE
GF    C004        72.2 DEGF    C005          69.2 DEGF

          C006        66.0 DEGF    C007          62.7 DEGF    C008         68.1 DE
GF    C009        66.7 DEGF    C010         125.6 DEGF

          C011       207.8 DEGF    C012         111.3 DEGF    C013        112.8 DE
GF    C014       124.4 DEGF    C015         128.5 DEGF

          C016        60.4 DEGF


          C017       134.1 DEGF    C018          77.2 DEGF    C019         78.5 DE
GF    C020         -.9 GAL     C021          69.4 GAL

          C022        75.7 GAL     C023          -4.6 GAL     C024      .066700 GA
L     C025     .504000 KWH     C026       30900.0 BTU

          C033     -597.54 BTU     C034        874.50 BTU     C035      2544.70 BT
U     C036       40.33 BTU     C037        -48.56 BTU

          C040     111687. DATE


****

NOW AT BLDG 812              FT. CARSON TIME IS 09:52:28
History files reset at building 812
F03/2

NOV16,87                                              CERL ECRSD B812 R6.3 MIN


09:52:33  C001        812.63 BLDG    C002          31.6 DEGF    C003         78.3 DE
GF    C004        83.8 DEGF    C005          77.6 DEGF

          C006        70.0 DEGF    C007          74.6 DEGF    C008         67.2 DE
GF    C009        74.8 DEGF    C010          99.4 DEGF

          C011       122.4 DEGF    C012         164.5 DEGF    C013        172.3 DE
GF    C014       204.4 DEGF    C015         214.2 DEGF

          C016        63.6 DEGF


          C017       160.1 DEGF    C018          90.1 DEGF    C019         88.6 DE
GF    C020         1.9 GAL     C021          67.9 GAL


          C022        66.[illegible] GAL     C023          1[illegible].5 GAL     C024      0.00000 GA
L     C025     .456000 KWH     C026       0.00000 BTU

          C033      350.89 BTU     C034       4374.15 BTU     C035      5330.48 BT
U     C036        0.00 BTU     C037        158.74 BTU

          C040     111687. DATE


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Figure B2. Sample RDASS activity log.

```
NOW AT BLDG 813              FT. CARSON TIME IS 09:55:25
History files reset at building 813
F03/2

NOV16,87                                                  CERL ECRSD B811 R6.3 MIN

09:55:30  C001        813.63 BLDG    C002          32.0 DEGF    C003          75.5 DE
GF    C004        77.5 DEGF    C005         78.0 DEGF

          C006         79.3 DEGF    C007          73.3 DEGF    C008          76.2 DE
GF    C009        64.0 DEGF    C010        115.7 DEGF

          C011        190.0 DEGF    C012         164.2 DEGF    C013         167.0 DE
GF    C014       181.9 DEGF    C015        198.8 DEGF

          C016         61.6 DEGF


          C017        167.1 DEGF    C018          82.3 DEGF    C019          78.4 DE
GF    C020         2.2 GAL     C021          70.6 GAL

          C022         70.8 GAL     C023          -9.7 GAL     C024     0.00000 GA
L     C025     .432000 KWH     C026      10300.0 BTU

          C033      1332.91 BTU     C034       1635.93 BTU     C035     9804.67 BT
U     C036        0.00 BTU     C037       311.01 BTU

          C040      111687. DATE



NOW AT BLDG 1361             FT. CARSON TIME IS 09:56:25
10 attempts made and failed.  Bldg 1361 is not talking.


NOW AT BLDG 1369             FT. CARSON TIME IS 10:02:31

''''''''''''''''''''''''''''''''''''''''
Reliable connection but no response from AG at bldg 1369, retrying
Bldg 1369 still has dead AG, aborting.

''''''''''''''''''''''''''''''''''''''''
Reliable connection but no response from AG at bldg 1369, retrying
Bldg 1369 still has dead AG, aborting.
AG responded this time.



''''''''''''''''''''''''''''''''''''''''

''''''''''''''''''''''''''''''''''''''''
Bldg 1369 did not respond to 'X', retrying
Still no response to 'X', aborting history file dump.

''''''''''''''''''''''''''''''''''''''''
Bldg 1369 did not accept date/time information, retrying

''''''''''''''''''''''''''''''''''''''''
Still unable to accept date/time, continuing with old date/time.

''''''''''''''''''''''''''''''''''''''''
Bldg 1369 did not accept 'G' command, retrying.
AG does not accept 'G', scan still stopped. Call Bldg manually!

****
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Figure B2. (Cont'd)

Responding to a Dynamic System

RDASS makes decisions appropriate to responses of the DAS in order to execute the data retrieval. If recognized error conditions exist, it takes remedial action. At each building, RDASS will establish that a 1200 baud reliable connection has taken place (signifying that the error checking modems have recognized each other). If it has not, the automatic system will hang up the phone and call again several times then skip the unit and proceed to the next building. RDASS will send a remote-command enable sequence to the Autograph and wait for an acknowledgement. If none is received, it will send out a control-Q sequence which will clear any control-S (wait) commands which may be on the communication lines. If appropriate acknowledgement is not received, it will hang up the phone and call again for ten tries. If transmission error occurs, a request for retransmission takes place between the IBM-AT and the data logger.

Sampling Data

Upon connection, the Autograph will be somewhere in its scanning cycle outputting minute data and hour data onto the RS-232 line as it is being gathered. On days when only minute data is sampled, RDASS will open a local file and allow this stream of information to be added for sufficient time to ensure that a complete 1-minute sampling period has occurred. It will then close the file and save it for later review. This passive method of data sampling is unobtrusive to the Autograph's gathering routine.

Transferring Files

On days when hour data is to be gathered, RDASS stops the Autograph from further scanning, uploads the hour and single minute history files to the AT, verifies that the files are nonempty, then resets the Autograph files, resets the date and time, and initiates data scanning. Although the Autograph will allow the uploading of history files without stopping the scanning routine, failure to stop scanning will result in a queuing of scanning instructions followed by a catch up pattern which may alter the sampling time period.

Formatting Information

RDASS formats the data as it is being retrieved to make it compatible with Symphony spreadsheets. To accommodate the 240-character field length limitations of Symphony, incoming data is parceled and alternately placed into one of two data files when the the amount of data per line is large. To make use of Symphony date and time functions, RDASS converts the standard date and time data into Symphony format. Additionally, RDASS removes extra line feeds and carriage returns in the data formatted for printer and screen display, thus leaving one carriage return and line feed after the last data point of a scan cycle. After this is done, data can be imported into Symphony with all data points for one hour on one line (one row of a spreadsheet). RDASS deletes extra space characters between data fields and at the end of data lines to further limit line length. Also, as part of processing on the fly, RDASS automatically strips the unit names (eg. degf, gal) from the data when retrieving files.

Night Operation

The system is configured to run at night to take advantage of central processing unit (CPU) availability, leaving regular working hours for interactive tasks. Further, nightly data retrieval increases operations reliability and speed since telephone lines are less busy and less noisy during the evening hours.

Identifying Signal Problems

After data retrieval, the hour and minute data are analyzed by RDASS to help the user identify signal and communication problems. Each data point is checked against a hierarchy of specified conditions. These conditions can be absolute, or calculated from other data points (single or multiple) using mathematical operations as well as logical operations. Data are inspected for signals out of practical ranges, for cross checks among related data fields, for values which indicate a specific hardware problem (such as open, short circuit, or reversed leads) and for trends over time (up to the last 60 hours) to verify that signals have not remained constant or zero or are incrementing in too repeated a pattern for extended periods of time.

Generating Reports

Initial data analyses result in two reports that organize the massive amount of data retrieved and facilitate the detection of signal and communication problems. A report is generated, from the single minute data, that informs the user if the date and time are correct and if any of the monitored parameters are out of range. A report generated from the hourly data is used to detect errors that can only be seen at the hourly resolution level or as trends (Figure B3).

Anomalies flagged by analysis of the reports are corrected by the system operator or a field technician.

Interactive Operation

Interactive (manual) data acquisition allows a system operator to perform individualized or nonroutine operations. This mode is employed to load programs and make special checks on systems flagged by the automated routine. Based on experience and knowledge of how the system is supposed to perform, the user can determine the condition of the system and also what type of action is necessary to correct a problem that may have occurred.

Summary

The RDASS system is a powerful tool for maintaining remote data acquisition. It reduces personnel requirements, frees up the computer, consolidates analyses, and reduces potential human error as it meticulously follows its instruction set for data retrieval and monitoring.

File: HM12NV87.W0
Scan: C:\AUTOCALL\MSCAN0
Date: 11-12-87

Column	St Row	End Row	Minimum	Maximum	Problem
0	1	70	78.15	81.60	Check Zn3 pump and P.T.: pump may be off or broken.
0	1	70	78.15	81.60	Delta temp. limit for Zone 3 exceeded. (L15)
0	1	70	-0.22	0.96	Warning !!!: No water in child water loop.
3	1	70	28.35	53.53	The outside temperature range.
10	4	35	80.05	84.94	Warning: South zone temp over practical limits. (L80)

File: HM12NV87.W1
Scan: C:\AUTOCALL\MSCAN1
Date: 11-12-87

Column	St Row	End Row	Minimum	Maximum	Problem
1	47	70	1649.80	1680.29	Short circuit on zone 2 flow.
1	3	27	1326.57	1387.80	Flow > pump rating in zone 2.
1	32	34	1316.27	1371.10	Flow > pump rating in zone 2.
1	37	42	1322.21	1388.11	Flow > pump rating in zone 2.
6	9	9	30.29	30.29	Building using too much electricity. (L30)
6	16	18	31.99	34.20	Building using too much electricity. (L30)
6	29	30	30.55	31.10	Building using too much electricity. (L30)
6	40	42	30.55	31.63	Building using too much electricity. (L30)
12	1	70	0.00	0.00	Zero BTUs in zone 3
24	1	70	0.00	0.00	Zero child water BTUs

Figure B3. Sample hourly status report for one building.

LIST OF ACRONYMS AND ABBREVIATIONS

AFM	Air Force Manual
AHU	air handler unit
ASCII	American Standard Code for Information Interchange (alphanumeric code commonly used in computers)
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
BASIC	Beginners All-Purpose Symbolic Instruction Code (computer programming language)
BLAST	Building Loads Analysis and Systems Thermodynamics (computer program)
bldg	building
Btu	British thermal unit
CDD	cooling degree day
COP	coefficient of performance
Cp	constant pressure specific heat
CPU	central processing unit
CT	current transmitter
cuft	cubic feet
CW	chilled water
DAS	Data Acquisition System
DAU	data acquisition unit
degf	degrees Farenheit (unit designator on temperature data)
DHW	domestic hot water
dia.	diameter
ECIP	Energy Conservation Investment Program
E_{ref}	energy used by reference building
ECRSD	Energy Conservation Retrofits for Standard Design (project)
ES	Energy Systems Division
E_{svgs}	energy savings
E_{tst}	energy used by test building
FSO	full scale output
FTAT	Facilities Technology Application Test
FTS	Federal Telephone Service
FY	fiscal year
ga	gauge
gal	gallon
gpm	gallons per minute
htg	heating
Hg	mercury
HDD	heating degree day
hr	hour
HVAC	heating, ventilating, and air conditioning (system)
HW	heating water
IR	interim report
K	thousand bytes of computer memory space
kBtu	thousand Btu
kWh	killowatt-hour
lb	pounds
m	volume of fluid
mA	milliamps
MBtu	million Btu
MHz	megahertz (million cycles per second)

MS-DOS	MicroSoft disk operating system
mV	millivolt
NAVFAC	Naval Facility
NOAA	National Oceanic and Atmospheric Association
OCE	Office of the Chief of Engineers
P	pressure or power
PC	personal computer
PROM	programmable read only memory
psi	pounds per square inch
psig	pounds per square inch gauge
PT	pressure transducer
Q	energy
R	resistance
RAM	random access memory
RDASS	Remote Data Acquisition Support System
RSS	root sum square
RTD	resistance temperature detector
sch	schedule
SIR	Savings Investment Ratio
s/n	serial number
SPSS	Statistical Package for the Social Sciences, Trademark of SPSS, Inc.
sq ft	square feet
SQRT	square root
T1, T2	temperatures
TR	technical report
USA-CERL	U.S. Army Construction Engineering Research Laboratory
V	voltage
wc	water column

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